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A STUDY OF INCINERATOR RESIDUE ANALYSIS OF WATER SOLUBLE COMPONENTS

DREXEL UNIVERSITY

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A STUDY OF INCINERATOR RESIDUE ANALYSIS OF WATER SOLUBLE COMPONENTS

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With the cooperation of the City of Philadelphia Department of Streets and Department of Public Health, the characterization and classification of incinerator residue was studied. The authors of this report examined the following objectives: (a)To establish procedural criteria for the rapid examination and evaluation of physical, chemical, and biological characteristics;(b)To determine potential public health nuisance conditions resulting from placing incinerator residue in land fills with particular attention to rodent attraction and propogation, fly and insect breeding, odor eminations, wind and water erosin, and stream pollution; (c)To determine the effect of the incinerator on the physical, chemical, and biological characteristics of residue; and (d)To determine the maximum amount of leachable material in incinerator residue.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

In an attempt to solve the problems involved in solid waste management, this report, published by the National Environmental Research Center - Cincinnati, attempts to characterize and classify incinerator residue.

Andrew W. Breidenbach
Director
National Environmental Research Center

FINAL REPORT

A STUDY OF INCINERATOR RESIDUE

Grant No. U100509

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FINAL REPORT

A STUDY OF INCINERATOR RESIDUE

Grant No. UI00509

Handling and disposing of solid waste materials creates a combination of health hazards and nuisance conditions. Incineration has been suggested as one method of rendering innocuous those portions of refuse which are responsible for undesirable environmental conditions. These undesirable conditions, which it is hoped that incineration will eliminate, include the attraction and breeding of animals, birds and insects, the emanation of odors and control of unsightly filling operations.

Not all portions of solid waste materials are implicated as contributors to the undesirable conditions. Household refuse is composed of a series of components which can be manually separated into broad groupings such as paper, wood, food waste etc. Most of the problems and nuisance conditions are the result of food waste or other decomposable organic materials including leaves and grass clippings. Odors and nutrients result from decomposition or fermentation of these organic materials, and it is this same fraction which serves as the food source for the attraction and propogation of vectors.

Numerous changes in today's society are compounding the problems of solid waste disposal. Changes related to increases in population density, continued population growth, more and larger regions of dense population, and changes in the quantity and character of refuse all figure materially in any waste management plan. The last component, that is the changes in refuse production, could possibly be altered by legislation, such as banning non-returnable bottles. It is doubtful that in the immediate future any rapid changes will evolve with respect to the character of generated refuse, but continued slow changes will persist.

Incineration of solid waste is practiced mainly in high population density areas, but, except in large mid-western and eastern cities, reliance upon incineration is not imperative. Incineration is required in those areas where no space for landfilling is available. Incineration is used mostly as a short-term disposal technique and little consideration is generally given to long term solid waste management plans. Hopefully, this archaic thinking will be altered in the future, and solid waste management plans will be formulated which offer both short and long term solutions.

The very fact that solid waste management plans are considering economic alternatives is a positive step. Comprehensive studies such as those for New Orleans and Fresno (U.S.P.H.S. 1969) serve to lay the ground work for the formulation of comprehensive plans.

Incineration is used where land is scarce because combustion offers the greatest volume reduction of solid waste. Volume reduction is beneficial in solid waste management systems and is a measurable economic advantage when equated to the cost of land; however, it is not possible to measure residue character in terms of volume reduction alone. There has been negligible reliable information available to describe the character of incinerator residue in terms other than volume or weight reduction.

Residue from incinerators is disposed of in a variety of ways. Residues are discharged to landfills, dumps or deposited directly upon open ground. A major problem of residue landfills is the continued burning (smouldering) of incompletely burned refuse. Other objectionable conditions include the harboring and attraction of rodents and insects, the emination of odors and smoke. Because of poor burnout and the resulting nuisance conditions, many municipal incinerators have been abandoned before amortization of construction costs. In these situations the municipality recouped only a small part of the capital investment.

Complications and problems arising from the necessity to ultimately dispose of incinerator residue have taken a sharp turn upward during the past several years. Formerly it was assumed that all incinerator residue was innocuous to the breeding of flies and insects and that the main purpose of an incinerator was for volume reduction alone. Today, however, we realize that this is not the case and that residue quantity and character does vary between incinerators and within the incinerators during the seasons of the year. If consistency of residue character is to be achieved, a system of classifying residue must be developed, and the classification system must predict whether nuisance conditions could result from improper disposal. Absence of characterization techniques has retarded the upgrading of incinerator performance. It is the absence of such techniques that forms the primary basis for this research project. Many of the goals set forth in the initial proposal centered around the development of characterizing incinerator residue.

RESEARCH GOALS

Specific objectives of this research project are as follows:

a) To establish physical, chemical and biological acceptability criteria.

b) To establish procedural criteria for the rapid examination and evaluation of physical, chemical and biological characteristics.

c) To determine potential public health nuisance conditions resulting from the placing of incinerator residue in landfills with particular attention to rodent attraction, and propogation, fly and insect breeding, odor eminations, wind and water erosion, and stream pollution.

d) To develop basic knowledge concerned with the ultimate use for residue.

e) To adopt standard methods for sampling, evaluating and predicting potential problems concerned with incinerator residue.

f) To determine the effect of incinerator operation on the physical, chemical and biological characteristics of residue.

g) To determine the maximum amount of leachable material in incinerator residue.

The most important goal of this research project is the development of analytical procedures which can be used to predict the physical, chemical, and biological character of residue. Several approaches to this goal have been considered, and after much deliberation it has been decided that the method used would not separate any material and the entire sample would be reduced to a size where chemical analyses are facilitated. Previous researchers, e.g. Kaiser (1964), and Bell (1960), utilized the approach of separating refuse into component groups or separation of metal and glass prior to grinding the paper and foodstuff.

While these approaches are applicable, within limitations, for analyzing raw refuse, it was felt that incinerator residue could not be separated manually. Hence, this technique could not be used. In the case of a well-burned incinerator residue, separation by visual observation cannot be accomplished.

Physical Analysis

Analysis of residue to determine its physical characteristics were chosen as a primary method of completing the description of residue. No specific goal prejudiced the choice of physical tests such as what final deposition would be expected.

Physical analysis including unit weight and moisture are especially important in determining materials handling techniques and in determining volume and weight reduction. When residue must be transported for final disposal, other physical characteristics may be considered. Because of the vast number of testing possibilities that could be developed, a limitation of technique had to be imposed. No measure of internal friction and compactibility were used. However, in place unit weights and laboratory unit weights were analyzed to determine the volume reduction expected during normal disposal operations.

Sampling Techniques

In order to analyze incinerator residue or raw refuse reliability in the analytical procedures and a firm knowledge that the true character of the entire sample has been determined must be expected. The problems associated with sampling refuse and residue are somewhat different, and the techniques for sampling each are presented in the appendix.

Raw refuse is more difficult to sample than incincerator residue because hopefully, the incineration process has reduced both the volume and weight of the raw material in excess of 75%. This means that the individual character of refuse is lost during burning. In addition there are more variables to be considered in raw refuse than in incinerator residue when one attempts to determine the character of the solid waste material.

Variables which are considered in refuse but assume lesser importance in residue are moisture and calorific value. These variables reflect the conditions which must be altered during incineration to insure that adequate burnout is achieved. High moisture content means more underfire air and a slower rate of burning is needed. For an incinerator using auxillary fuel, high moisture content could also necessitate pressing into service the fuel.

Incinerator residue is easier to sample since the residue is more homogeneous than refuse. Incinerator residue will be saturated with moisture after quenching, and, as such, sampling procedures need not preserve the moisture content as in sampling refuse. One important objective in sampling incinerator residue is to preserve the organic material, that is the non-consumed combustible material which is present. In submerged quench systems much of this matter is removed by flotation or washing during quenching. The second important determination in characterizing residue involves the quenchification of the inorganic material. Complicating the inorganic quantity is the fact that soluble salts dissolve in the quench water. If only the environmental nuisance characteristics of residue are considered then the salts in the quench water need not be considered. However, in a properly operated spray quench system the material is not removed and the soluble salts can be leached from the residue when it is placed on the land surface. For the purposes of this study, salts which are leached from the residue during quenching was considered to be part of the process water system. Quench water and spray water used for the control of air pollution are considered to be incinerator process waters and constitute a problem considered to be a liquid industrial waste. Treatment of the process waters is a problem of general concern which lacks an acceptable solution.

Biological Studies

Very little information exists to prescribe what precautions must be taken when residue is deposited on the land for ultimate disposal. Speculation has been expressed ( ) as to when residue can be deposited directly on the ground and when residue must be landfilled in a sanitary manner.

The problems associated with land deposition include the attraction and propogation of biological vectors including rats, insects, roaches and vermin. In addition biologically degradable materials can emit odors to the surrounding atmosphere. The attraction of vectors and the emission of odors are one set of criteria which can be used in determining whether or not residue can be deposited directly on the land without being covered with an inorganic soil.

Control of vectors and odors underly the sacrosanct sanitary landfill criteria. No consideration is given to the use of residue as a cover material for sanitary landfilling. Some states, e.g., Pennsylvania ( ), specifically prohibit the use of residue as a cover material, without determining whether residue deposited on the open ground does cause undesirable nuisance conditions.

Studies were conducted at two locations in the City of Philadelphia to determine the problem extent when residue is deposited on the land surface. One of these locations involved the placement of residue on a land surface in a shallow zone, that is, the thickness of residue was about five feet. No cover material was placed on the residue and natural stabilization was allowed to occur. By stabilization it is implied that the decomposable material was allowed to oxidize biologically and no effort was made to influence the natural environment such as diverting rainfall from the surface. Samples were continuously taken for detection of biological vectors. The emission of odors and the growth of plants on the surface was also monitored. The second study was performed at an operating landfill where residue was being placed. No effort was made to control the landfill operation, odors and biological vectors were monitored. Because of the active nature of the landfill it was not possible to study the growth of surface plants until after the landfill ceased active filling.

Leaching Studies

As was stated earlier, incinerator residue which has been quenched at the termination of the incineration process has had many water soluble materials removed. However, not all of the matter is removed, and it is possible that after field placement many inorganic compounds can be leached from the residue by rainfall percolating through it. Residue which has not been totally burned could retain certain inorganic ions in a combined form. Decomposition could result in the freeing of certain ions for leaching. It is assumed that sanitary landfills receiving only raw refuse will eventually produce leachate. The quantity of matter which can leach from residue will depend upon the presence of organic decomposable material and the type of quench system. In addition to leaching from rainfall a second type of leaching occurs when residue is placed in a tidal area. Leaching which occurs from rainfall is intermittent and is a function of the frequency and intensity of rainfall. In a tidal zone, such as would occur in an estuary, it is suggested that residue can be used as a fill material behind permeable bulkheads. The kinetics and quantity of matter which are leachable must be studied to determine whether a concentration of inorganic material will cause estuary pollution. Studies were conducted to determine the quantity of matter which could be leached over several tidal cycles.

Effect of Operation

One function of this study was to determine the variations in character of incinerator residue. In addition to the character of refuse charged to the incinerator, residue character is a direct function of incinerator operation. One can sample many incinerators and find that the character of the residue discharged will vary daily and between identical furnaces constructed side by side. A reason for this variation is the incinerator operation mode, and the ability of operating personnel to use the equipment available. A study was conducted at one incinerator to determine which conditions are most influential in determining the incinerator residue character. The parameters which were studied include the amount of excess air, distribution of overfire and underfire air, and the rate at which material was charged to the furnaces. The incinerator used was a continuous feed furnace so that the charge rate could be specifically studied.

Special Study

One study involved cooperation with the Township of Whitemarsh, Montgomery County, Pa., and the U.S.P.H.S. Demonstration Grants Branch for a study of the incinerator operation at the Whitemarsh Incinerator. During the test operation the incinerator was controlled and monitored for air pollution emissions, sampling and analysis of refuse and residue, and charging rate. Residue analysis and analysis of the process waters were performed in this study.

The results of the joint study at Whitemarsh are presented in a report of the Roy F. Weston Company, Inc. to the United States Public Health Service in fulfillment of Grant No. DO-1-UI-00089. Some of the results are included in this report.

General

The entire study was carried out in conjunction with the City of Philadelphia Department of Streets and the Department of Public Health. The Philadelphia Department of Streets is responsible for the collection of refuse and for its ultimate disposal. As part of their disposal techniques the city operates six incinerators. They cooperated fully by allowing sampling and operating the incinerators. Because of this complete cooperation, all of the results are reported and no analyses have been withheld which might prejudice the results. The large number of samples reported in Volume 2 of this report indicates the number of samples which were needed to gain statistical validity. These samples were obtained under random operating conditions and a wide variety of climatological conditions.

The Department of Public Health cooperated in assessing the vector attracting characteristics of the material and performed the entymological studies. Field studies were performed on fly and rodent attraction.

Closure

Determining the character of incinerator residue and assessing its physical and biological qualities is no trivial task. The following chapters of this report give some preliminary findings of the results of this study. While this is the final report of the study, it is assumed that the findings are preliminary. What has been done is to establish those areas which are troublesome and those areas which one need not be concerned. The following chapters briefly state the findings of the study and lists the results and conclusions which were determined. It must be emphasized that the data which was generated can be interpreted by many people. We have attempted to supply all pertinent details of methods and analysis. Methods of obtaining data and all variables which may affect the interpretation of the results are also given.

II. SOLID WASTE GENERATION AND DISPOSAL

In the daily pursuit of the necessities of living --- food, water, and shelter --- man produces many byproducts which are of no further use to him and, thus, must either be recycled into the manufacturing or reclamation systems as raw materials or disposed of in some manner. The character and composition of household byproducts[1] will be different from the speciality byproducts of commercial and industrial establishments. Except for only a few constituents the domestic byproducts have limited reclamation value, and as such, their disposal represents an economic burden placed on the individual homeowner or industry. When the byproducts have no reclamation value they are called wastes.

Household waste products which require disposal are generally limited to the solid and liquid states. Only in rare cases are domestic or household wastes generated in the gaseous state. The handling and disposal of domestic liquid wastes is well documented, and excellent treatments of the subject are found elsewhere (10, 11). Only solid waste material will be included in the discussion of the results presented in this dissertation.

---

[1] The terms domestic, household, and residential will be used interchangeably in all discussion. It should be recognized that there is a slight difference in meaning of each category, however, the discussion presented is sufficiently broad so as not to require a more detailed definition.

The disposal of domestic solid waste[2] can assume many different forms, and the method chosen for a given locality is primarily the result of economics. Other variables including the quantity of waste and land availability, together with local site considerations such as geology, hydrogeology and demography, should also be considered in the disposal method selection. Most communities have either municipal or private refuse collection with the responsibility for ultimate waste disposal by the collector.

After domestic waste has been collected, the ultimate disposal is accomplished by selection of one of a variety of methods. The results of a recent survey (24) indicate that the most widely used method of waste disposal in the United States is by "landfilling", and is estimated at 40 percent for all solid waste generated. Following "landfilling" in order of greatest use are "open burning" (35 percent), "poor incineration" (10 percent) and "good incineration" (5 percent). The definition of "good" and "poor" is left undefined, and this lack of definition proves that as recently as 1967 no system of refuse or residue characterization existed.

The burning of domestic refuse in "designed" incinerators has been practiced since circa 1870 (14), and the acceptability of incineration as a disposal method has often been severely questioned. Incineration has alternately been condemned and lauded as a method for the disposal of solid waste material. Condemnation of incineration is often related to poor air pollution control and secondarily to other environmental problems including noise, dust, odor, and fly control. Many of these secondary problems can be attributed to the dumping of improperly burned residue on the land in the proximity of the incinerator. No information is available upon which to base a criteria relating physical, chemical and biological character and the occurrence of these secondary problems.

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[2] Solid waste is sometimes referred to in the plural, as well as by other synonyms such as refuse. The terms rubbish and garbage carry a specific inference and are not to be considered synonyms with solid waste or refuse. Rubbish is the non-putrescible part of solid waste, and garbage is the putrescible portion. Solid waste includes all non-wanted by-products in the solid phase, and can even include incinerator residue.

Residue possesses characteristics related to the completeness of combustion. The waste being burned has a set of physical properties which include density, particle size and moisture content. Solid waste also has chemical characteristics which include a separation into combustible and non-combustible components.

Before any attempt is made at defining the characteristics of either incinerator residue[3] or unburned refuse, the character of the residue is assumed to be included in one of three categories:

1. The residue characteristics are similar to raw refuse. This is to say, very little combustion occurs, and the residue resembles the unburned refuse.
2. The characteristics can't be changed extensively by combustion. In order for residue to fall into this category it is required that the combustion be nearly complete. Most combustible material is consumed leaving an inorganic residue.

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[3] The terms ashes and residue are sometimes used interchangeably. The term ash is not to be confused with the term ashes. For a discussion of the terms see the paper by Schwartz (32).

3. Only partial combustion occurs and the residue has characteristics common to both previous categories. Most residues will fall into this category.

In category 1 the residue contains large quantities of combustible material such as wood, paper and cardboard. The combustible fraction includes substances which can decompose under the influence of microbial activity, and thereby create secondary solid and gaseous products. Some of these secondary products, alcohols from fermentation, etc., are the medium for further microbial activity. If the microbial decomposition is anaerobic, undesirable odors can be emitted to the atmosphere. The decomposable substances also form the food supply for the attraction and propagation of animals and insects.

Category 2 is the ultimate in residue character. All combustible material is destroyed and only inorganic compounds remain. However, inorganic compounds in the residue may be soluble in water. Thus, surface water percolating through the landfill as a result of rainfall, can leach these compounds from the residue.

Depending upon the extent of combustion, the characteristics of category 3 residue could result in environmental interaction. The similarities with the character of category 1 residue will depend upon the percent of combustible matter consumed during incineration.

Unless residue or a fraction of the residue is recycled as in its use as a construction material or in metal salvage, it must be ultimately disposed of in some manner. Thus, incineration is not a complete disposal process, but rather only a method of refuse modification.

Awareness of the complications and problems arising from the necessity to ultimately dispose of residue from all three categories has taken a recent turn upward. At one time incinerator residue was assumed to be relatively innocuous to the breeding of flies and insects (10), and that the main purpose for incineration was volume reduction. Today, however, it is realized that this is not the case (29). Residue character[4] will vary with the incinerator construction, raw refuse character and efficiency of incinerator operation. Of these factors affecting the character of residue, the type of incinerator construction, or more specifically the type of design, is the factor which is the most apparent. A look at the types of equipment used in the construction of each design will enumerate the basic differences in design.

INCINERATOR DESIGN

There are several types of furnace configurations and designs which are in prevalent use in the United States. All incinerators built in the United States are divided into two categories: batch and continuous feed systems. Prior to 1940 practically all incinerators were of the batch feed type (35). Continuous feed types have come into widespread use since about 1950, although the concept of continuous feed existed earlier. The first continuous feed unit in the United States was constructed in Atlanta, Georgia in 1938 (35) and was of the rotary kiln design. The first traveling grate incinerator was built in New York City in 1953 and is called the Gansevoort Incinerator (35).

The basic differences between batch feed and continuous feed incinerators is summarized by a brief description of the process. Batch feed incinerators do not have a continuous flow of refuse both into and through the combustion chamber; the flue gases are continuously removed but the system must be opened intermittently to allow refuse to be charged and residue to be removed. Thus, batch feed systems impose severe limitations on maintaining steady state operation because of the necessity to open and close the inlet and outlet of the incinerator. When the charging or discharge gates are opened, furnace temperatures show a decrease because of convective air flow through the furnace.

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[4] The terms quality, character, and composition are used to describe residue and refuse. Composition refers to specific items such as paper, metal and glass. Character included composition plus a description of some general properties including density, moisture and chemical constituents. Quality infers classification according to measurable parameters.

The continuous feed system in contrast to the batch feed system allows charging of refuse and removal of residue from the furnace continuously. The charging hopper connects to a chute, which also serves as an air seal, and does not allow back drafts of convective air into the combustion zone.

In order to minimize air leakage at the discharge end, several methods have been used to continuously remove the residue from the closed furnace. One method employs the use of double discharge gates. The gates are opened alternately; the residue being removed from the hopper through the bottom gate while the top gate remains closed. When residue is discharged from the furnace to the hopper, the opening of the gates is reversed.

TYPES OF GRATE SYSTEMS

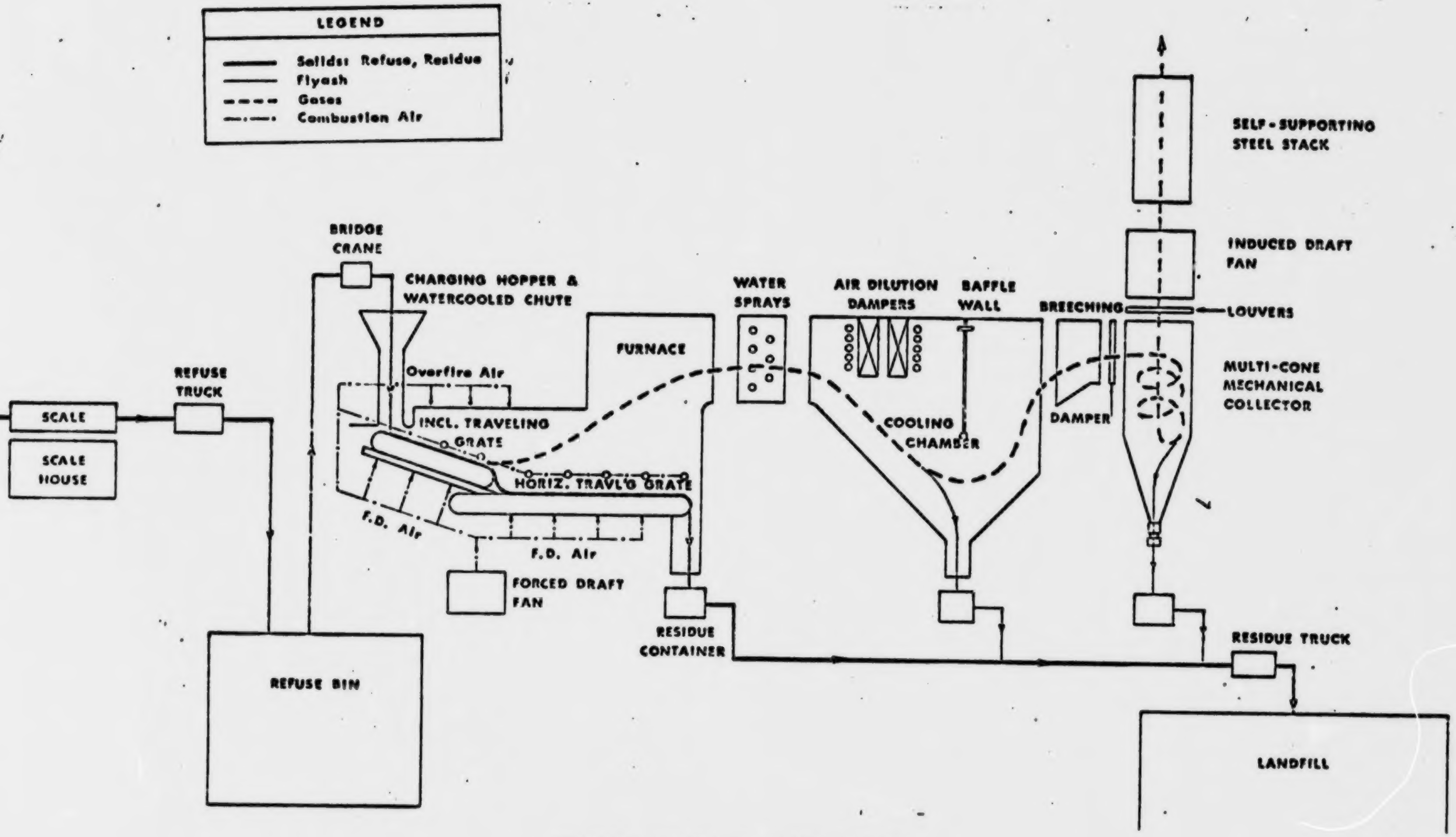
In addition to the choice of batch or continuous feed construction, incinerator designers can choose from several different types of grates. Grate systems are chosen with respect to the type of process and furnace configuration; i.e., either batch or continuous feed incinerators and the geometric configurations of the furnace.

The traveling grate system, which consists of an endless chain grate driven by a sprocket wheel, can only be used in conjunction with a continuous feed furnace. Incinerators using this type of grate are constructed using either a single stoker or several stokers in series. A common type of construction has two stokers in series; one being horizontal and one being inclined (35). The inclined grate is called the drying and ignition grate, while the horizontal grate is called the burning grate. Figure II - 1 is a side view through an incinerator using an inclined and horizontal stoker in series.

The reciprocating grate and rocking grate systems are two other forms of stokers commonly used. Both of these types can be interchanged between batch and continuous feed systems. The furnace enclosure must be rectangular, and as with the traveling grate system, either type of grate system can consist of either a single or multiple grates in series.

Reciprocating grates and rocking grates agitate the refuse bed more than traveling grates during combustion. This bed agitation encourages greater exposure of the burning surface. Recent studies (34) showed that bed agitation or large quantities of underfire air can entrain more particulate matter in the flue gas. The possibility of whether or not one system produces more entrainment of particulate matter must not be the determining constraint in selecting a grate system. Rather, the final decision should be determined by the results of intensive investigations on the quality and character of the residue which can be obtained from a given furnace design. This is to say, if a substantial amount of combustible material remains in the residue, then the incinerator has not performed its function.

The previous discussion on grate selection related to continuous


LEGEND
Solids: Refuse, Residue
Flyash
Gases
Combustion Air
SCALE
SCALE HOUSE
REFUSE TRUCK
REFUSE BIN
BRIDGE CRANE
CHARGING HOPPER & WATERCOOLED CHUTE
Overfire Air
INCL. TRAVELING GRATE
HORIZ. TRAVL'G GRATE
F.D. Air
F.D. Air
FORCED DRAFT FAN
FURNACE
RESIDUE CONTAINER
WATER SPRAYS
AIR DILUTION DAMPERS
BAFFLE WALL
COOLING CHAMBER
BREECHING
DAMPER
LOUVERS
MULTI-CONE MECHANICAL COLLECTOR
INDUCED DRAFT FAN
SELF-SUPPORTING STEEL STACK
RESIDUE TRUCK
LANDFILL

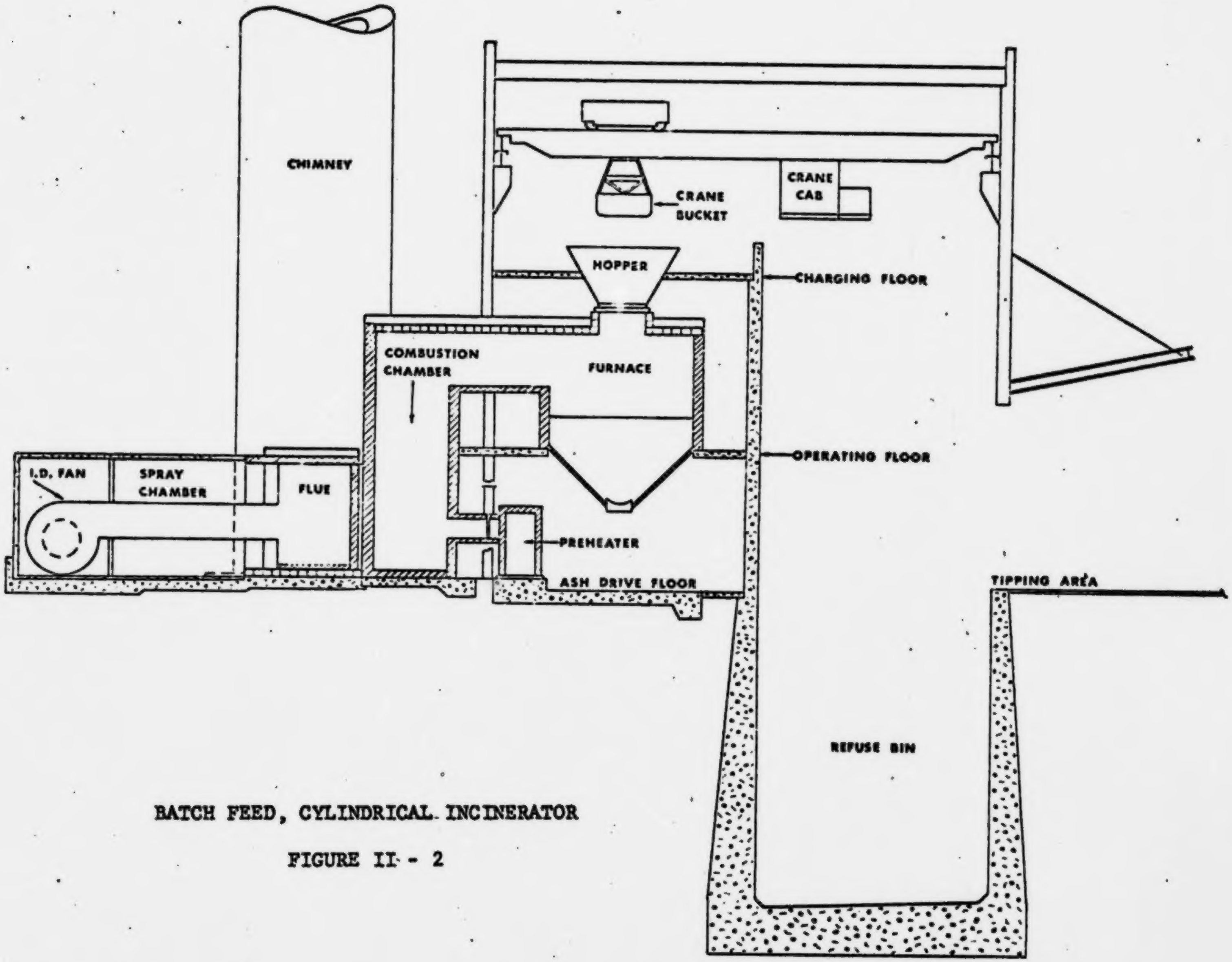
TRAVELING GRATE INCINERATOR
FIGURE II - 1

feed furnaces. For batch feed furnaces several types of grate systems can also be used. Whereas the trend today is toward rectangular furnace configurations (35), batch feed furnaces are often of a cylindrical shape. The early cylindrical furnaces were often stoked manually, although the newer incinerators use mechanical stoking by rotating rabble arms. The residue is stoked to the outside perimeter of the circular grate where it is intermittently discharged to a hopper located directly below. The refuse is charged, then allowed to burn, with the result being a continuously varying furnace temperature distribution. The uneven temperature distribution contributes to the variability of the completeness of combustion. Figure II - 2 shows a typical batch feed, cylindrical furnace.

Batch feed incinerators are also constructed with a rectangular configuration. Reciprocating grates or rocking grates are generally used in batch feed furnaces when the configuration is rectangular. In this type of design the grates are often manually controlled rather than relying upon the operation associated with continuous feed designs.

The increasing concern for attaining maximum burnout, and the possible development of residue criteria, have prompted engineers to add more retention time to new furnace designs. Examples of this trend include the use of three chain grates in the new Milwaukee incinerator. Instead of adding a third traveling stoker, a rotary kiln hearth can be used. This type of burning system is being considered for Allentown, Pennsylvania and Delaware County, Pennsylvania.

The rotary kiln seldom is used alone, but is used in conjunction with other grate systems. It is usually the final stage in the transport system through the combustion zone. Kilns are solid refractory lined hearths, and the residue is moved through the kiln by the rotation of the


CHIMNEY
CRANE BUCKET
CRANE CAB
HOPPER
CHARGING FLOOR
COMBUSTION CHAMBER
FURNACE
OPERATING FLOOR
I.D. FAN
SPRAY CHAMBER
FLUE
PREHEATER
ASH DRIVE FLOOR
TIPPING AREA
REFUSE BIN

BATCH FEED, CYLINDRICAL INCINERATOR

FIGURE II - 2

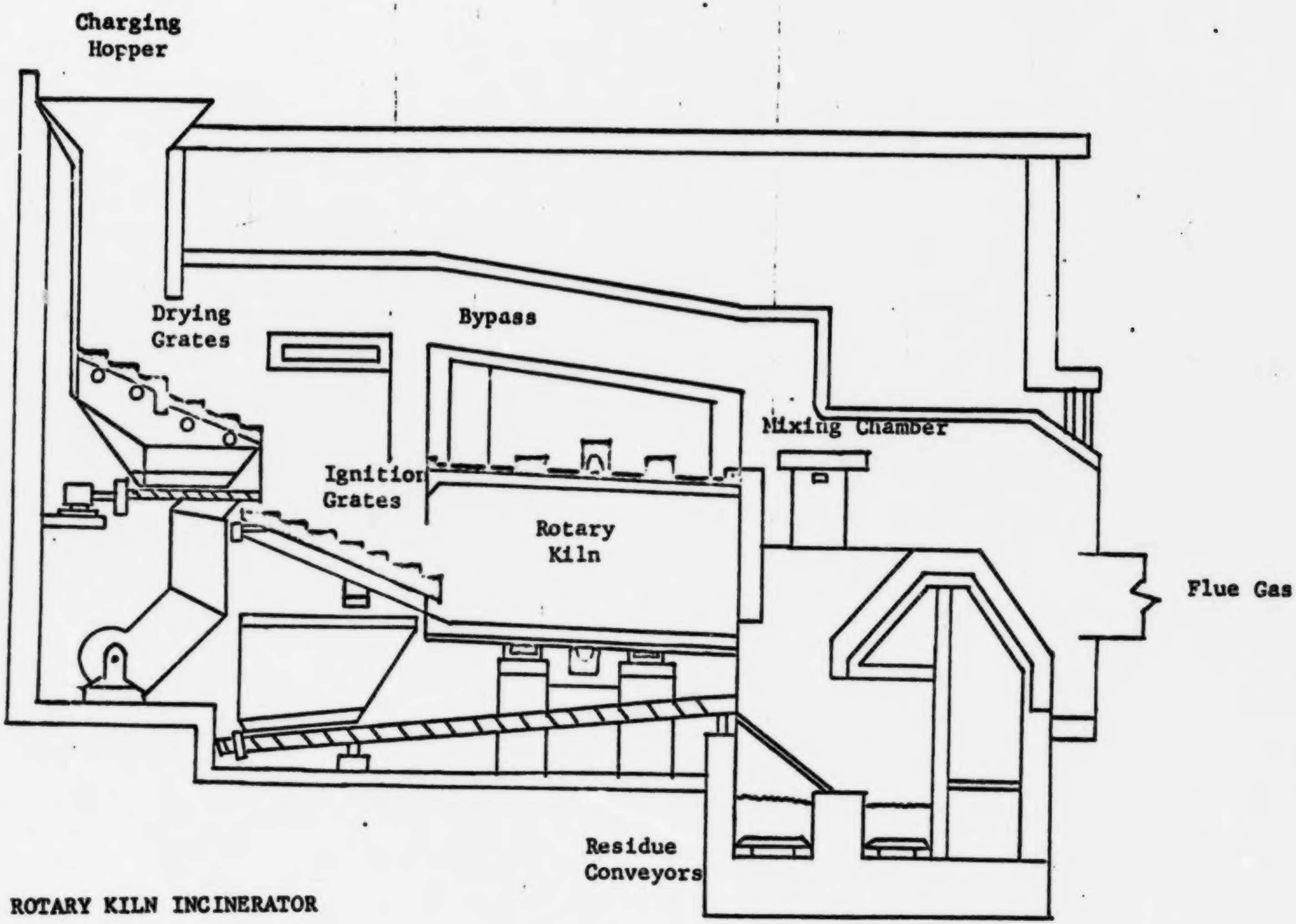
unit which is constructed with a downward slope. A typical incinerator facility using a rotary kiln in conjunction with reciprocating grates is shown in Figure II - 3.

EFFECT OF OPERATION ON RESIDUE CHARACTER

In addition to the type of construction and design of incinerators, operating methods contribute to the overall effectiveness. Not all incinerators have the same degree of operating flexibility. Better operation of an individual plant should result when the components are selected with optimization of operating flexibility in mind. The furnace operating parameters which should be variable include the grate speed, forced and induced draft, and the use of auxiliary fuel.

The operating parameters of an incinerator are somewhat determined by the incinerator design. Operation determines the amount of excess air and point of application of air depending upon the moisture content of the refuse. The grate speed determines the refuse retention time, and thus, the furnace temperature. While operation of the incinerator contributes to the character of residue, the raw refuse charged also has a direct bearing on the character of the residue and on the operation of the incinerator.

The nature of the raw refuse which is burned influences the character of the residue because of the wide variety of components in the waste. The diversity of substances is increased when the refuse includes domestic wastes as well as commercial and/or industrial wastes. Many commercial wastes are similar in character to domestic refuse, except that the concentration of a given constitutent will probably be biased. This is to say, the amount of paper may be higher from one commercial establishment than would be found in the normal domestic population, or


Charging Hopper
Drying Grates
Bypass
Ignition Grates
Rotary Kiln
Mixing Chamber
Flue Gas
Residue Conveyors

ROTARY KILN INCINERATOR

FIGURE II - 3

the amount of food waste may be greater than one finds in the household waste. By contrast, most industrial wastes are unique in character, and if they are to be burned in an incinerator, special analyses are required. In most instances, industrial wastes are of different character than domestic refuse.

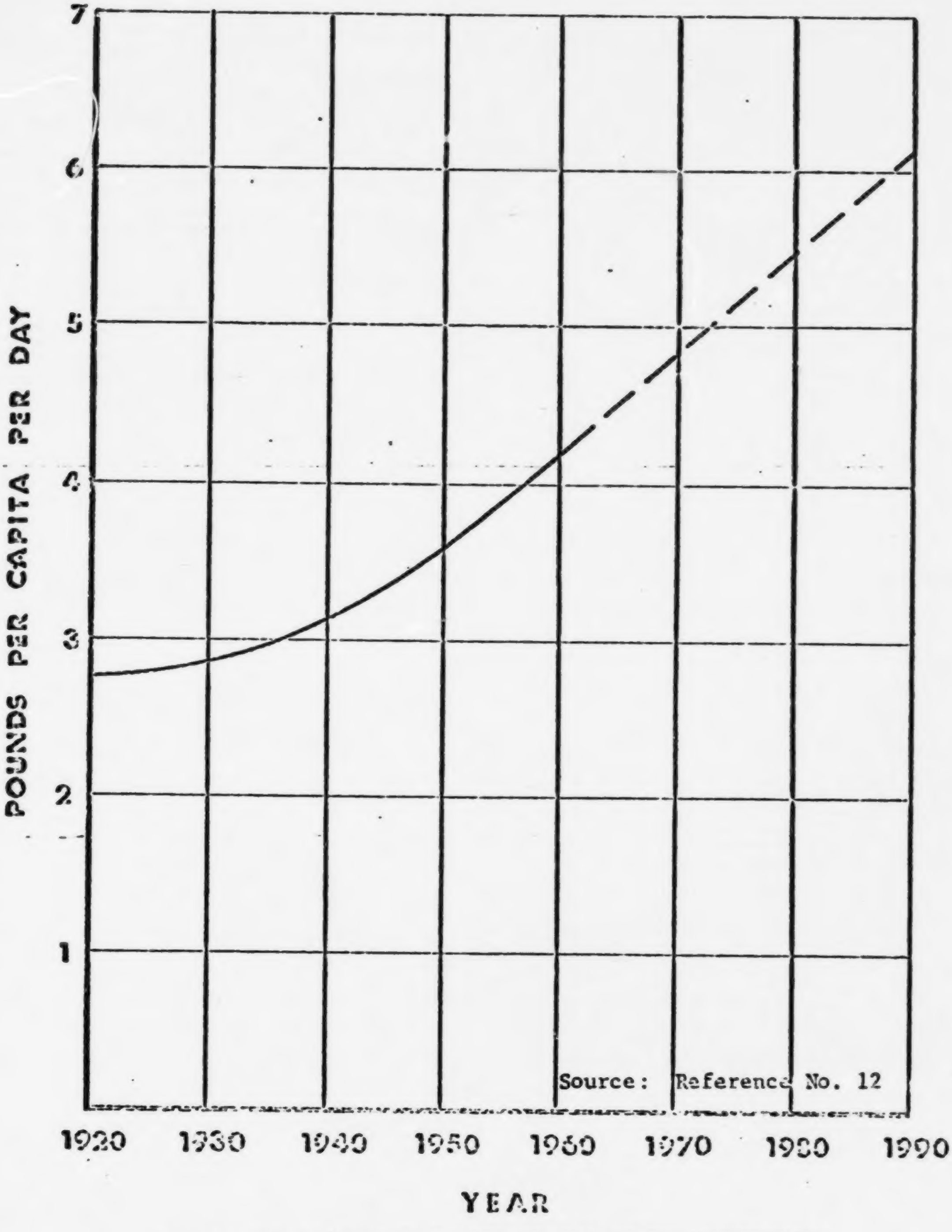
GENERATION OF SOLID WASTE

The character and amount of solid waste generated varies among communities, from rural to urban areas and with the geographical location (22). The quantity of waste which is produced in the United States is estimated to vary from 2.5 pounds per capita per day to thirty five pounds per capita per day (39). The lesser figure includes only solid waste which is produced by individual households and does not include any commercial or industrial waste. The thirty five pound per capita value includes, in addition to domestic waste, commercial waste, industrial waste, construction waste, and agricultural waste. These figures represent a range which exists throughout the United States.

Figures II - 4 and II - 5 show Refuse Production Trends and Per Capita Production Trends in the United States during the period from 1920 to 1965. These two curves also project trends to the year 1990.

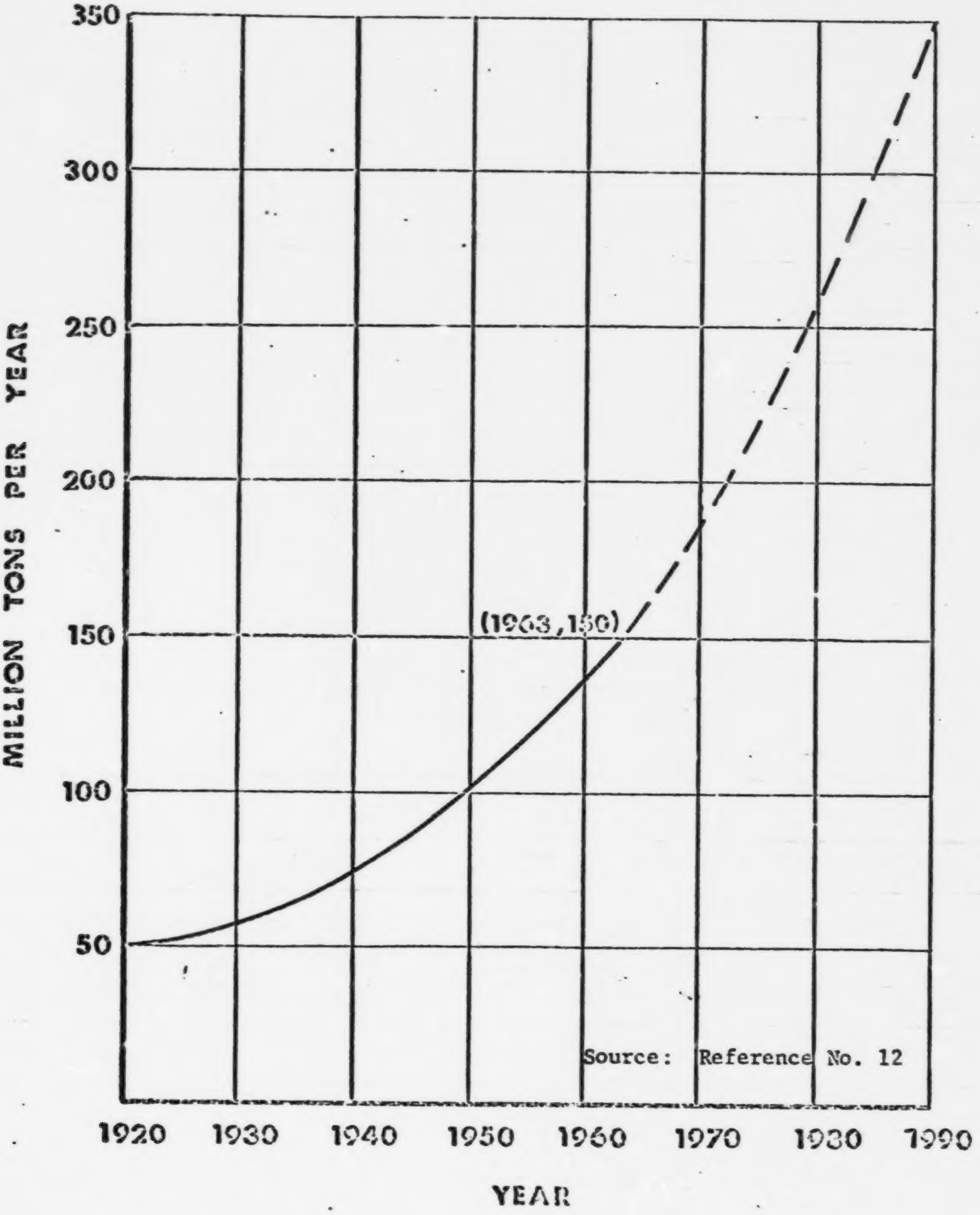
From Figure II - 4 it can be seen that the per capita refuse generation in 1966 was 4.5 pounds and is expected to reach six pounds per day by 1988. The total refuse production is expected to reach 300 million tons per year in 1985 which is double the 1963 production in a period of twenty-two years. The 1966 average of 4.5 pounds per capita is the nation wide average and local deviations are to be expected. This deviation has been measured as high as 25 percent (22).

The problem of agricultural waste disposal will not be discussed



UNITED STATES' TREND IN PER CAPITA REFUSE PRODUCTION

FIGURE II - 4



REFUSE PRODUCTION TRENDS IN THE UNITED STATES

FIGURE II - 5

in this thesis, although the volume of waste produced by agriculture is greater than the sum of all other sources (38). Agricultural waste is more homogeneous than domestic refuse and is usually biodegradable. Because agricultural wastes are degradable, handling and disposal are more easily controlled. Other types of solid waste, including domestic refuse, are more heterogeneous and their disposal must be more carefully planned in order to minimize environmental interaction.

Demolition waste consists of a combination of combustible and non-combustible components. The non-combustible components include building rubble consisting of brick, stone, dirt, gravel, and concrete. Some wood, a combustible, is present, but its total weight is much less than the other components. Because of the overwhelming non-combustible character of demolition waste, it is better to exclude delivery of these components to a municipal incinerator.

Other demolition waste can be expected during specific periods of construction, e.g. clearing and grubbing. These wastes include trees, brush, grass, and limbs which are combustible but difficult to handle because of their physical size. It is also better to exclude these wastes from a municipal incinerator.

The type and quantity of industrial and commercial wastes generated will vary with the nature of the industry and commercial establishments situated in the community. Some industrial wastes, e.g., the wastes from abbatoirs and meat packing houses, are very difficult to burn and many municipalities are reluctant to accept responsibility for disposal of this type of waste. Only combustible industrial and commercial wastes should be accepted at a municipal incinerator.

COMPOSITION OF SOLID WASTE

The method chosen for disposal of solid waste must be compatible with the composition of the waste. Domestic waste can be separated into its components, and the frequency of occurrence of each component, e.g., percent of paper, can be estimated by repeated separation of many samples over a period of time. Several separation schemes have been proposed in making estimates of the various groupings. Kaiser (17), Hickman and Kennedy (15) and Schoenberger (31) have proposed components into which refuse can be separated. A comparison of the three proposals is given in Table II - 1.

The twenty separations used by Kaiser represent much component overlap. The separation according to Hickman and Kennedy groups plastic, rubber and leather as one component. These items are quite different in composition and character. The separation scheme of Schoenberger is a compromise between the two proposals.

The separation of solid waste into components according to one of the three schemes represents one way of describing the composition of refuse. However, a separation procedure is tedious and expensive. Large samples must be chosen in order to obtain an accurate cross-section of the composition. Many replicate samples are needed to statistically define class intervals.

In his work Kaiser (17) averaged four man days in separating one ton of refuse. After separation, additional time is required to perform analytical determinations on each fraction. For example, Kaiser performed the "proximate" and "ultimate" analyses (2) on all twenty categories. These analyses performed on the components do not reflect any interaction between the components. In this thesis an alternate procedure

TABLE II - 1

CLASSIFICATION SCHEMES FOR SOLID WASTE

(1) Kaiser (17)	(2) Hickman and Kennedy (15)	(3) Schoenberger (31)
Newspaper	Paper Products	Ferrous Metals
Brown Paper	Foodwaste	Other Metals
Trade Magazine	Metals	Glass and Ceramics
Corrugated Paper Box	Glass and Ceramics	Rubber
Plastic Coated Paper	Garden Waste	Rags
Waxed Milk Cartons	Wood	Wood and Cardboard
Paper Food Cartons	Textiles	Paints, Oils and Solvents
Junk Mail	Plastic Rubber and Leather	Plastic
Vegetable Food Wastes	Ash, Dirt, and Dust	Leather
Citrus Rinds		Animal and Vegetable Waste
Cooked Meat Scraps		Other Paper Waste
Fresh Fats		Dirt
Leather		Miscellaneous
Composition Rubber		
Dirt		
Evergreen Cuttings		
Wood		
Flower Plants		
Grass		
Tree Leaves		

for establishing the quality of solid refuse and incinerator residue is presented.

The work of Kaiser was limited to the analysis of unburned refuse. Also the only analytical tests used were the ultimate and proximate analyses. These techniques constitute a limited testing procedure designed to estimate the fuel properties of the sample. A more comprehensive testing procedure which also includes estimating potential environmental interaction and incinerator effectiveness was devised.

This approach does not require a separation of the waste. It is assumed that separation of residue according to scheme is not feasible. Thus, the scheme presented in Section III involves the grinding of a sample of solid waste in an effort to facilitate the analytical techniques and to obtain greater sample homogeniety. The analytical techniques which were chosen are designed to describe the overall character of residue and solid waste, and not be limited simply to the fuel character of refuse.

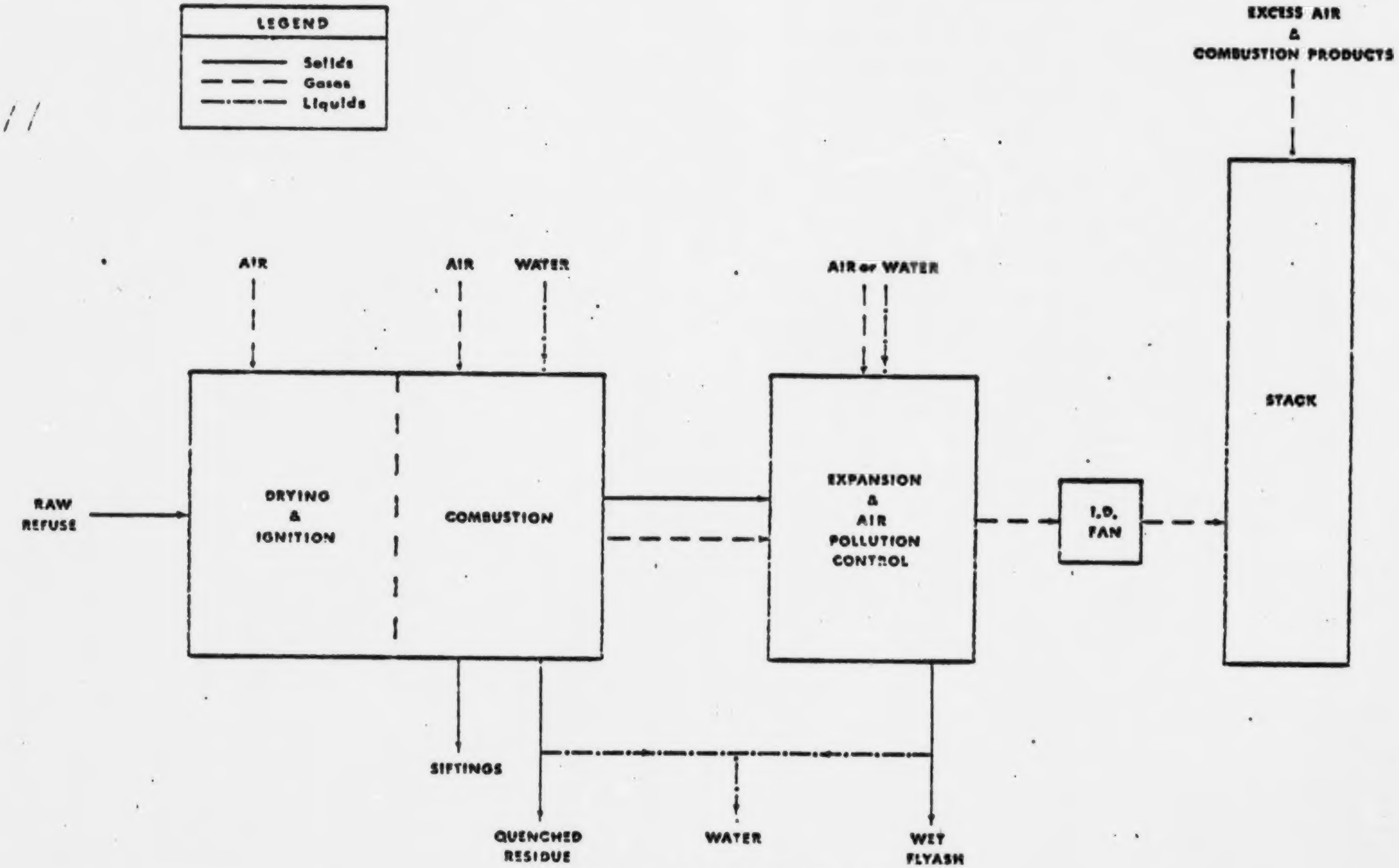
The incinerators which were studied and the results given in Section IV of this dissertation includes two units similar to Figure II - 1, one unit similar to Figure II - 2, and two units similar to Figure II - 3. In addition, there was studied one unit similar to Figure II - 1 that used reciprocating grates instead of traveling grates. This unit was also of the batch feed type rather than of the continuous feed type.

III. TECHNIQUES OF CHARACTERIZATION

In order to apply a method of characterization to solid waste or incinerator residue, it is necessary to define the ultimate goals of a characterization scheme. This report is specifically concerned with the character of solid waste as it is received at an incinerator, and with the character of the residue which is discharged from the incinerator.

All incinerators are constructed according to designs which perform the unit operations necessary for combustion. Figure III - 1 lists the flow processes and unit operations which are used in the burning of solid waste. Not all incinerators use the same flow processes; thus, some, but not necessarily all of the operations shown in this figure are found in each incinerator. For example, not all incinerators have induced draft fans. Draft can also be obtained by building tall stacks and controlled through the use of dampers.

Figure III - 1 shows only one point of solid waste input to the incinerator, but as many as four solid outputs are possible: residue, undergrate siftings, collected flyash, and particulate matter entrained in the flue gas. Of these outputs residue is the largest amount. The percent of flyash and siftings depends upon the type of air pollution control equipment and the type of grates. For example, the amount of siftings from a rocking grate with 1.93 percent open area has been estimated in one test to be 0.36 percent of the refuse charged (moisture free). The same type of grate having an open area of 24.5 percent, produced siftings totaling 8.49 percent of the refuse charged (21). The efficiency of air pollution control equipment used in controlling emissions from incinerators is well documented.


LEGEND
Solids
Gases
Liquids
AIR
AIR
WATER
AIR or WATER
EXCESS AIR & COMBUSTION PRODUCTS
RAW REFUSE
DRYING & IGNITION
COMBUSTION
EXPANSION & AIR POLLUTION CONTROL
I.D. FAN
STACK
SIFTINGS
QUENCHED RESIDUE
WATER
WET FLYASH

SCHEMATIC - INCINERATION PROCESS

FIGURE III - 1

Determination of the character of all the solid outputs from an incinerator is desirable for two reasons. First, the character of the residue can be compared with the unburned refuse to evaluate the effectiveness of the incinerator. Second, the character is useful in prescribing which methods for disposal of residue can be used, and what are the sources of potential environmental interaction. With these criteria as the goal of a characterization scheme, the selection of methods can now begin.

SELECTION OF METHODS

Defining the character of residue and refuse according to environmental interaction can be done with one of several ultimate goals in mind. There can be an interaction between residue and the underground or surface waters. In this case the interaction will probably be of a chemical nature, primarily the dissolving of chemical ions and compounds into the water. The effect of the interaction on water quality depends upon the ion or compound which is leached and its concentration.

A second interaction exists between residue and the biological life of the landfill. The attraction, propagation and harboring of microorganisms, insects, birds, and mammals are all affected by the interaction. It is difficult to separate biological interaction from normal conditions if the interaction is small. Also, the chemical interaction is related to the biological interaction which makes the total interaction extremely complex.

A beginning point for comparing the properties of raw refuse with incinerator residue is the percentage of combustible matter in each.

The percent of consumed combustible matter is one measure of the overall effectiveness of incineration operation. Effectiveness does not relate solely to the reduction in combustible material, but also includes other parameters which might relate to potential interaction.

To fully analyze the character of incinerator residue several methods will be used. The reduction in combustible material will be one technique used to evaluate the effectiveness of an incinerator. Other analyses include the heating value, water soluble fraction, ether soluble fraction, carbon and hydrogen.

Several methods of possible value in analyzing residue or refuse are included in the following discussion, and Appendix A contains the analytical procedures for performing each test. Not all of the procedures discussed have been used, but they are considered because of their potential role in measuring environmental interaction. The potential role is discussed.

MOISTURE CONTENT

The amount of water which is contained in refuse is variable and depends upon the composition and pertinent external conditions which influence the moisture content. Climatic conditions are influential and the duration and intensity of rainfall affect the moisture content of refuse. The moisture content is also affected by the percent of foodwaste and the weight of grass and leaves. Moisture from grass, leaves, and foodwaste is redistributed by absorption and adsorption onto the dry components in the refuse. Materials such as paper have a high absorptive capacity and water from the foodwaste and leaves is rapidly transferred to the paper.

Kaiser (18) shows that the moisture content for individual components in his separation scheme varies from no moisture in glass to almost

80 percent in foodwaste and other vegetable matter. When rainfall occurs water in the refuse is increased as a result of exposure during collection. When moisture increases, the unit weight of the refuse is increased and the weight of refuse collected on a wet day will be greater than the average daily tonnage. The added weight of water increases the burden on the incinerator equipment, and a longer furnace retention time is needed to dry the refuse before combustion can begin.

Evaporation of the water from refuse can require up to 13 percent of the heating value in the refuse. If dry refuse is assumed to be composed of cellulose (having a heat of combustion (Δh_c) of 4179 calories per gram dry weight),[5] the heating value of dry refuse is 7520 Btu per pound. If one pound of dry refuse is contained in a mixture having a 40 percent moisture content, the total weight is 1.67 pounds and the weight of water is 0.67 pounds. In order to evaporate this weight of water, approximately 654 Btu or about 8.6 percent of the available energy is needed to dry the refuse. Refuse is not composed totally of cellulose, and the heating value is about 5000 Btu per pound instead of the 7520.

The analytical determination of moisture in residue and refuse can be performed by using several methods. Since raw refuse contains an undetermined quantity of low boiling point compounds, an extraction technique using xylene is proposed. None of the low boiling point compounds are lost with this method.

Determination of moisture in residue can be done using the conventional drying procedure at 100 degrees Centigrade. This method is faster and less cumbersome to perform than the xylene extraction method. Both techniques plus the Karl Fischer method are presented in Appendix A

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[5] See page 307 of Reference 16.

Two methods were evaluated to determine the amount of water present in incinerator residue: (1) oven heating and (2) the standard xylene method. In the former case the residue samples are weighed, placed in a 110°C oven for 1 hour, cooled in a desiccator and then reweighed. The percent moisture of the samples is then determined by weight difference. In the standard xylene method the samples are refluxed in xylene (boiling point = 140°C) for 45 minutes. The weight of water in a sample is determined from the volume of water (1 ml = 1 gram) which collects in a graduated glass tube.

The purpose of this study was to determine if there is a significant difference between the results obtained by the two methods. It is theorized that a difference may exist due to the possible separation of chemically-bound water in the case of the standard xylene treatment.

The data used in this study was obtained from the analyses of 27 samples of incinerator residue - each sample having been taken on a different day and not necessarily from the same incinerator. The oven heating analyses involved either 4 or 5 fold replication and the xylene method 4-fold replication (Data are presented in Table III-1). The comparison of means method based on sample variances[1] was used in comparing the results of the two treatments (39)

Statistical conclusion: There is not a significant difference between the results obtained by the oven heating and standard xylene methods.

TAPLE III - 1

MOISTURE DETERMINATION DATA, PERCENT BY DRY WEIGHT

			PERCENT WATER				
NO.	SAMPLE	TREATMENT	1	2	3	4	5
1	NE	1	33.24	32.67	42.87	26.97	34.15
		2	34.40	31.40	33.42	29.35	-
2	NE	1	73	12.96	12.29	11.31	-
		2	13.16	12.94	12.58	11.71	-
3	NE	1	39.20	40.90	44.70	40.00	40.40
		2	51.07	53.32	55.42	49.89	-
4	NE Flyash	1	46.19	43.18	45.97	44.29	45.40
		2	49.77	48.30	49.63	50.72	-
5	NE Flyash	1	49.03	46.51	44.49	47.48	42.47
		2	50.56	50.60	51.55	51.42	-
6	Delco	1	27.42	25.89	24.25	25.59	21.48
		2	24.32	27.46	24.89	21.96	-
7	Delco	1	32.49	34.10	34.63	32.44	34.40
		2	27.84	26.74	29.72	30.37	-
8	NW	1	22.42	29.26	25.88	25.62	-
		2	28.80	29.10	24.70	24.40	-
9	NW	1	26.57	25.80	25.77	26.76	23.63
		2	27.35	24.44	26.50	27.10	-
10	NW	1	30.20	30.21	29.31	30.00	31.02
		2	34.73	35.32	35.39	36.33	-
11	NW	1	6.58	6.45	6.40	4.51	7.39
		2	5.74	4.94	3.96	4.98	-

DATA (CONTINUED)

12	NW	1	20.59	20.73	20.97	17.18	16.55
		2	22.82	21.87	19.46	20.91	-
13	NW	1	16.98	14.78	14.43	14.18	13.14
		2	18.58	18.73	21.44	18.24	-
14	NW	1	16.82	18.96	15.69	12.03	16.38
		2	14.49	16.13	13.66	17.80	-
15	NW	1	17.57	18.61	18.69	19.54	22.31
		2	18.33	17.72	17.31	17.47	-
16	NW	1	17.00	16.97	18.82	14.82	15.77
		2	14.68	16.65	16.63	16.95	-
17	NW	1	9.66	9.34	9.92	9.34	11.78
		2	15.70	13.52	12.63	9.50	-
18	NW	1	22.20	19.43	22.74	25.04	23.53
		2	17.88	21.64	22.16	21.66	-
19	NW	1	3.84	3.31	3.36	3.21	4.69
		2	3.55	3.88	3.25	3.68	-
20	NW	1	3.66	4.20	3.61	3.96	3.82
		2	2.61	3.26	2.82	3.63	-
21	NW	1	23.64	23.25	22.98	24.33	21.97
		2	24.15	24.32	23.57	22.24	-
22	EC	1	19.40	18.57	16.88	16.93	18.43
		2	19.01	17.42	17.63	18.97	-
23	Atlanta	1	11.90	12.50	11.02	9.61	10.85
		2	10.71	10.15	10.81	10.79	-
24	Atlanta	1	35.56	39.33	42.03	41.48	36.32
		2	42.51	43.54	44.83	52.94	-

DATA (CONTINUED)

25	Atlanta	1	18.88	18.95	19.21	19.01	18.72
		2	18.70	19.30	19.78	19.71	-
26	Louisville	1	21.91	20.42	20.77	20.70	20.52
		2	21.63	21.13	22.22	20.72	-
27	Miami	1	24.26	17.06	17.92	18.82	19.86
		2	20.81	23.75	15.76	21.44	-

TABLE - III-2

SUMMARY OF STATISTICAL RESULTS

OVEN DRYING VS. XYLENE EXTRACTION

	Percent Average	Standard Variance
Oven Drying	22.31	136.86
Xylene	23.50	186.18

General conclusions

Considering the statistical conclusion, it appears that the standard xylene method does not remove a significant amount of chemically bound water - if in fact it removes any at all. However, before one can be certain that the above is true, two questions should be considered: (1) Is the incinerator residue completely free of volatile matter? (2) Are the sample populations normal as required by the comparison of sample means test.

If any volatile matter is present in the incinerator residue, the oven heating treatment will give high results for percent water. However, due to the nature of the standard xylene method, the results obtained using this treatment will not be affected in the above manner. Therefore, the possibility exists that chemically bound water is being removed by the xylene method but this is not apparent because of the loss of volatile matter in the oven heating treatment.

The residue samples may contain lumps of metal. If these lumps are present in a sample, the percent water in that sample will be lower than normal. The presence of metal lumps will thus give results whose distribution curve is skewed to the left. If the distribution curve deviates significantly from the normal case, the comparison of means method, which was used in this study, is not valid. The data used in this case is not sufficient to test the sample populations for normalcy. It was therefore assumed that the sample populations are normal.

CHARACTERISTICS OF SOLID WASTE AS A FUEL

The fuel characteristics of coal and coke are determined by using the methods of the American Society for Testing materials. The methods for coal and coke (ASTM, D 271 - 58) are divided into two separate procedures called the "proximate" and "ultimate" analysis. The ASTM methods are not necessarily applicable to solid waste, but they can be used as the basis for developing a set of modified techniques.

The ultimate analysis of coal and coke includes a quantitative determination of carbon, hydrogen, sulfur, nitrogen, moisture, ash, and oxygen. All of these elements are determined directly except oxygen which is estimated as the difference between 100 percent and the sum of the other elements. For coal or coke the results are mostly computed on a moisture and ash free basis (MAF) (28). Other methods of computing results include on an "as received", "as fired" and "air dried" basis.

An elemental analysis of solid waste shows a higher percentage of oxygen than that reported for coal. In solid waste the combustible material consists mostly of carbohydrate compounds. This includes sizable quantities of cellulose ans sugar. Carbohydrates have oxygen in their molecular structure, which means that more oxygen will be determined in the ultimate analysis than would be determined in the analysis of coal.

The percentage of oxygen is important for the ultimate analysis of coal is used to estimate the heating value and in stoichiometric calculations. The Dulong Formula (28) is based on the ultimate analysis and is used to compute the heating value of coal. The formula is empirical and a quantity called "net hydrogen" is computed from the percentage of hydrogen and oxygen. Net hydrogen implies the hydrogen remaining after the available oxygen has been combined to form water. Because of the large percent of carbohydrate in solid waste, the net hydrogen correction is invalid for solid waste.

f it is assumed that solid waste is composed mostly of organic material, then the percent of carbon, hydrogen, sulfur, and oxygen is important in the stoichiometric balance. Solid waste does consist of large quantities of organic material, and also has a measurable percent of non-combustibles. When these non-combustible components are intermixed with the combustible fraction, the result is to dilute the percentage of carbon and hydrogen and reduce the heating value of refuse.

In refuse carbon and hydrogen are found mostly in cellulose and lignin, the basic components of paper, wood, and cardboard. Cellulose is an organic compound having the general chemical formula $(C_6H_{10}O_5)_x$, where x is some number between 100 and 200 (30). The carbon/hydrogen ratio in cellulose is 7.14, and analyses of refuse reported later, indicate that the combustible fraction is present in a form having this ratio.

A comparison of the carbon/hydrogen ratio in refuse and incinerator residue could possibly be used in predicting incinerator burnout. Because of the predominance of cellulose in the raw refuse (20), it is expected that C/H ratio of 7.14 would be closely approximated. However, as the resistivity to thermal decomposition rises, the resistant, but burnable compounds, will remain in the residue. As is shown later, the carbon/hydrogen ratio in residue will be higher than the ratio in refuse.

The applicability of the ultimate analysis to solid waste characterization is doubtful. Several of the elemental determinations, such as carbon and hydrogen, are useful both in coal and solid waste analysis, however, the results of ultimate analysis as constituted for coal cannot be applied to refuse without modification. The American Society for Testing Materials method for the determination of carbon and hydrogen is presented in the Appendix (2).

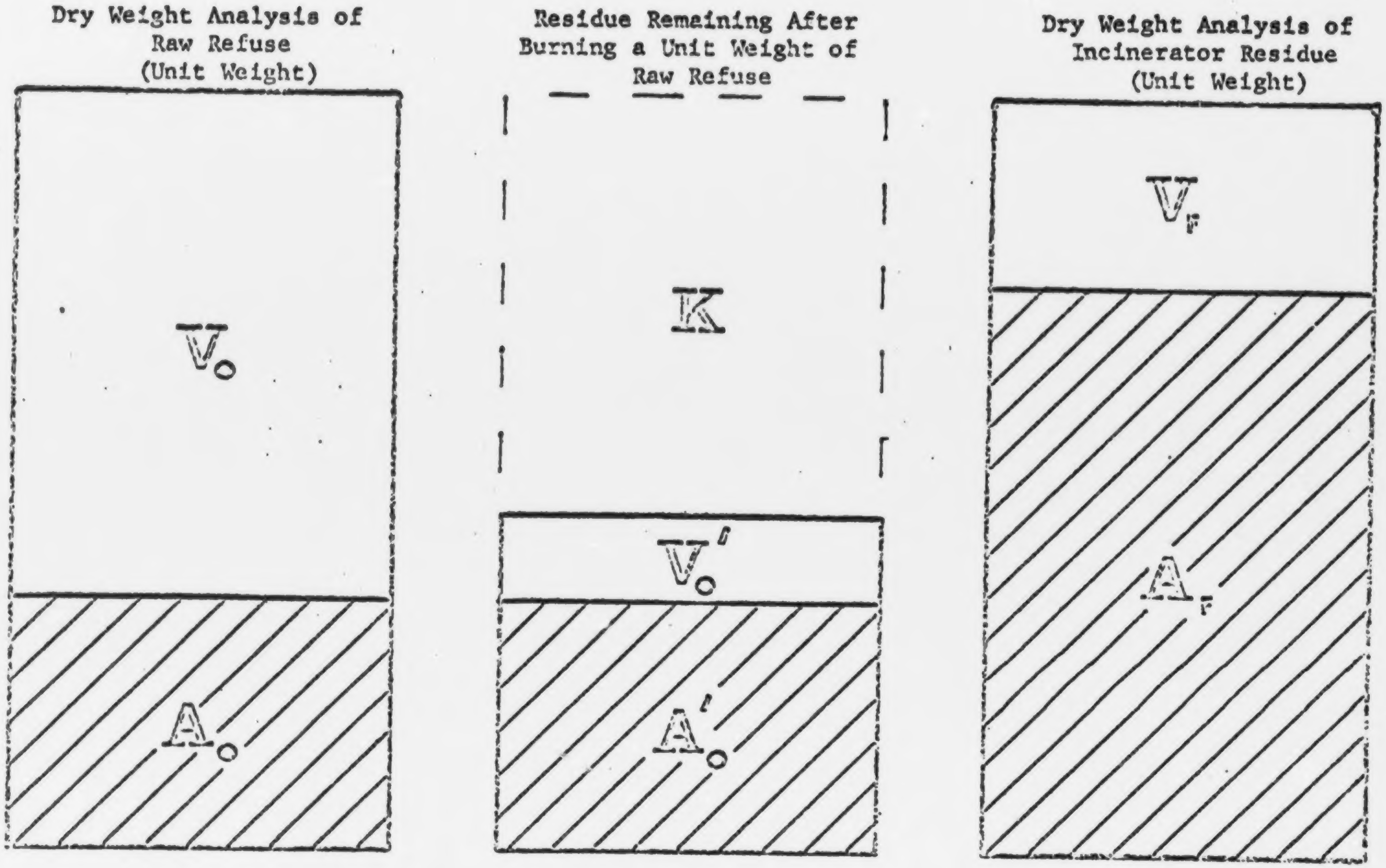
COMBUSTIBLE MATTER AND ASH

In the proximate analysis of coal the terms volatile matter and ash hold a specific connotation. The proximate analysis for coal includes the analytical determination of volatile matter, ash, fixed carbon, and moisture, and its name is derived from its use in approximating the ultimate analysis. Because refuse does not contain much fixed carbon the term combustible matter will be used to include both volatile matter and fixed carbon.

In the analysis of refuse or residue for the combustible fraction, the fraction which is not combustible is called ash. The analytical techniques for determination of combustible matter and ash are not too complicated, but data interpretation can be misleading as a result of slight modifications in technique. The ASTM method for coal specifies the use of a closed crucible in determining the volatile percentage. The closed crucible is used to prevent oxidation of elemental carbon and pyritic compounds, and thereby expelling only the volatile fraction. In refuse analysis combustible matter is defined to include all the volatile material, free carbon and combined carbon. It is necessary to encourage carbonaceous oxidation by keeping the crucible uncovered during the analysis. Obviously, the combustible matter reported using an open crucible is not analguous to the volatile matter when a closed crucible is used.

The combustible percentage can be used to predict incinerator effectiveness and the ash fraction is important because it represents the least amount of residue that results from incineration. Kaiser (17) also stated that residue acts as a heat sink and is used to carry large quantities of heat from the furnace.

The ash fraction is composed of glass, ceramic material, dirt, and metals. Trace quantities of other minerals are also present. While the components comprising the ash fraction are considered inert, the metals can undergo oxidation in the furnace. The oxidation process involves an overall weight gain for metals. Because oxidation is encouraged during


Dry Weight Analysis of Raw Refuse (Unit Weight)
Residue Remaining After Burning a Unit Weight of Raw Refuse
Dry Weight Analysis of Incinerator Residue (Unit Weight)
V_o
A_o
K
V_o'
A_o'
V_f
A_f

$V_o + A_o = 1$ $\qquad$ $V_o' + A_o' = 1 - K$ $\qquad$ $V_f + A_f = 1$

THE RELATIONSHIP BETWEEN UNBURNED REFUSE AND INCINERATOR RESIDUE

FIGURE III - 2

the analytical determination of the combustible fraction, a possible error results. The small percentage of metals in refuse indicate that any error will be small.

The percentages of combustible matter and ash can be determined for both incinerator residue and raw refuse. When these percentages are expressed on a moisture free basis, a relationship between refuse and incinerator residue can be derived. Referring to Figure III - 2, the effectiveness of burning, as estimated using only the percent of the combustible matter in residue can be given by the following relationship:

$$P = (V_f \ / \ A_f + V_f) \times 100 \text{ --------------------III - 1}$$

Where P is the percent combustible remaining in the residue, V_f is the weight of combustible matter per unit weight of residue and A_f is the weight of ash per unit weight of residue.

Equation III - 1 is an estimate of the effectiveness of an incinerator if the combustible and ash fractions are known for a sample of residue. This estimate of effectiveness is crude and refinements to the procedure can be developed.

The actual percent of combustible matter which has been destroyed per unit weight of refuse cannot be calculated directly until the relationship between the (1 + x) pounds of refuse which are burned to yield one pound of residue is developed.

If reference is again made to Figure III - 2, it can be seen that V'_o and A'_o are related A_f and V_f by direct proportion, so that;

$$\frac{V'_o}{V_f} = \frac{A'_o}{A_f} \text{ ----------------------------------III - 2}$$

V'_o and A'_o are respectively the ash and combustible percentages in the residue after combustion of one unit weight of refuse. It is not possible to analytically determine either of these quantities, although the effectiveness of operation can be stated as the ratio $V'_o / A_o + V_o$.

The weight reduction during incineration is K. Thus,

$$A'_o + V'_o + K = A_o + V_o \text{ ------------------------III - 3}$$

The weight of ash left after burning a unit weight of refuse (A'_o) should approximate A_o, so that by definition of the writer A_o equals A'_o. After making this assumption, Equation III - 2 can be rewritten as follows:

$$V'_o = A_o V_f / A_f \text{ ------------------------------III - 2A}$$

Equation III - 2A is an expression for the weight of the combustible fraction remaining after combustion of a unit weight of raw refuse. The equation is in terms of measurable quantities, that is, the ash and combustible fractions of the refuse and residue.

Recognizing the identity of A_o and A'_o, Equation III - 3 becomes:

$$V_o = V'_o + K \text{ ----------------------------------III - 3A}$$

Transposing K,

$$V'_o = V_o - K \text{-----------------------------------III - 3B}$$

Combining Equations III - 3B and III - 2A yields:

$$V_o - K = \frac{A_o V_f}{A_f} \text{ -------------------------------III - 4}$$

At this point the term, "percent of burnout", is defined. Burnout is defined as the weight percent of combustible matter which has been consumed in the process of combustion. It is defined as:

$$B = \frac{K}{V_o} \times 100 \text{---------------------------------III - 5}$$

where B is the percentage of burnout of combustible matter. The burnout is 100 percent when K is equal to V_o. Burnout is an indicator of incinerator efficiency, and this is the term for which a solution is sought.

Equation III - 4 when solved for K has the following form:

$K = (V_o - A_o V_f / A_f)$ ----------------------------III - 4A

Substituting into Equation III - 5, one obtains an expression for burnout defined by terms for which laboratory tests are available.

$B = (1 - A_o V_f / A_f V_o) \times 100$ --------------------III - 6

The factor A_o / V_o is the weight ratio of the ash to combustible percent in refuse on a moisture free basis. It may not be possible to accurately measure A_o / V_o because a large sample of refuse must be taken in order to obtain a reliable average. However, when A_o / V_o has been determined by many sample analyses, this ratio can be substituted into Equation III - 6 as a constant.

Based upon the figures of Kaiser (20), separation of refuse into its components gives a figure of about 60 percent combustible. When the ratio A_o / V_o equals 0.67, the refuse has a concentration of 40 percent ash and 60 percent combustible. A ratio of this magnitude was also reported by Purdom et. al. (29).

If the percent of ash and combustible are obtained for residue, but satisfactory data for refuse composition are not available, then the suggested A_o / V_o factor of 0.67 can be inserted as a constant in Equation III - 6.

$B = (1 - 0.67 V_f / A_f) \times 100$---------------------III - 7

To determine whether there is a difference between covering and uncovering the crucibles when determining "loss on ignition" a sample sequence was devised. The sequence used not only covered and uncovered crucibles, but also temperatures of 400, 600, 800 and 900 degrees C were used.

Procedure

Three samples of residue and solid waste are weighed (dry), placed in an oven for two hours, and reweighed. The percent loss in weight is determined. Samples B and C are subjected to temperatures of 400°C, 600°C, 800°C, and 900°C, while sample A is subjected to only the first 3 temperatures. At each temperature each sample is subdivided into 6 crucibles so that 3 of the crucibles are covered and three are uncovered.

The following is a statistical analysis to determine: (a) if there is any significant difference between the covered and uncovered percentages for all samples at all temperatures; (b) if there is any significant difference between the covered samples and the temperature; and (c) if there is any significant difference between the open samples and the temperatures.

To do this the method of analysis of variance with three factors was chosen. The three factors are the samples (A, B, C), the temperatures, and whether the samples were open or covered which will be abbreviated O-C. The fact that sample A had been run with only 3 temperatures, necessitated running variance test twice; once using 3 samples (A.B.C.) and 3 temperatures (400, 600, 800) while the other test was run with 2 samples (B, C) and all four temperatures.

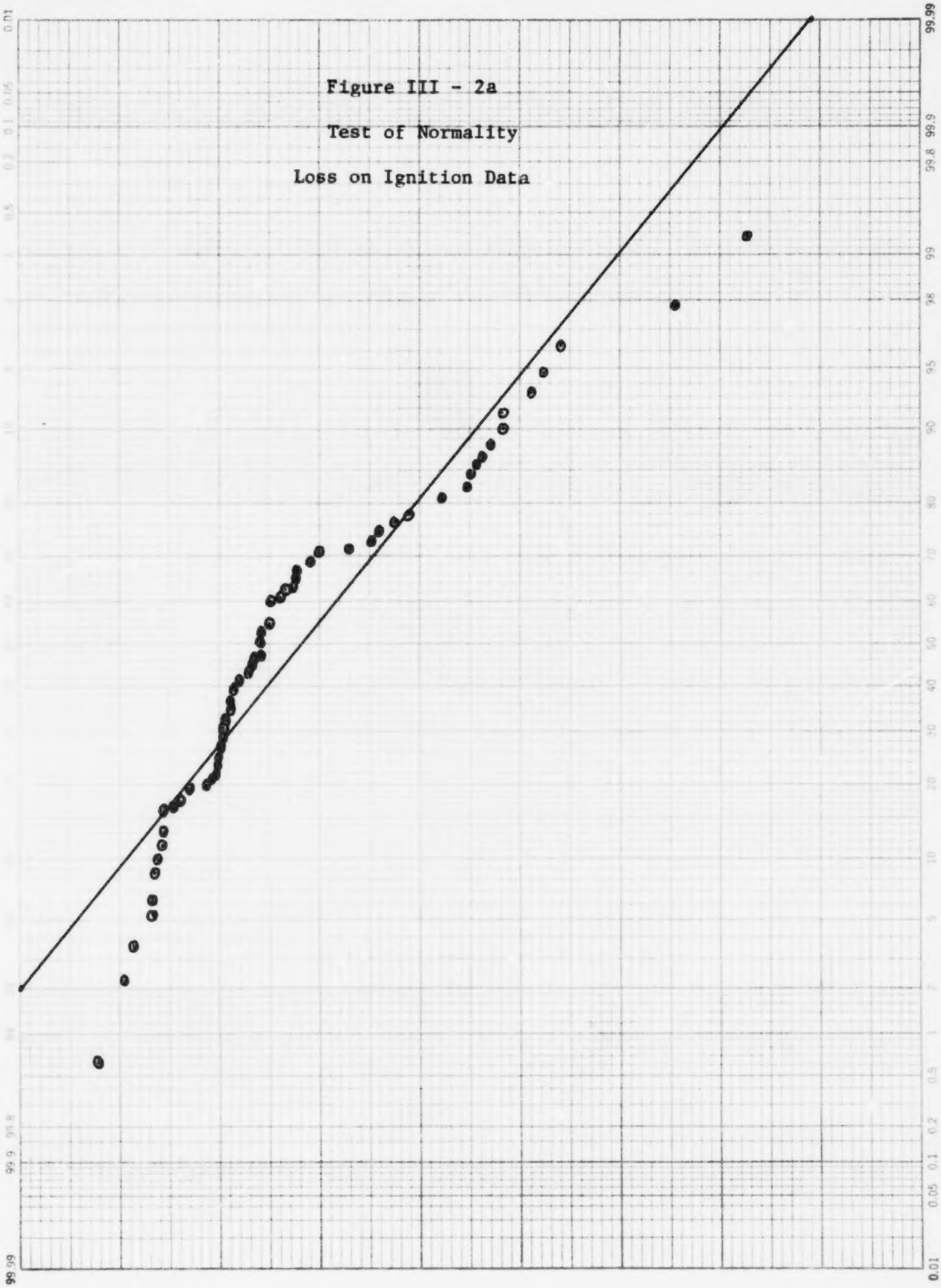


Figure III - 2a

Test of Normality

Loss on Ignition Data

TABLE III - 3

COVERED VS. UNCOVERED DATA
LOSS ON IGNITION
(PERCENT OF DRY WEIGHT)

Uncovered	Test 1				Test 2				Test 3				
Temp.	A	B	C	Total	A	B	C	Total	A	B	C	Total	Total
400	21.0	10.9	5.23	37.13	18.2	9.18	5.70	33.08	20.5	10.6	5.78	36.88	107.09
600	18.0	11.9	9.62	39.52	16.9	9.95	8.16	35.01	15.7	8.20	7.94	31.84	106.37
800	18.5	9.64	10.00	38.14	18.0	7.75	9.73	35.48	21.7	10.8	8.64	41.14	114.76
Tot.	57.5	32.44	24.85	114.79	53.1	26.88	23.59	103.57	57.9	29.6	22.36	109.86	328.22
Covered Temp.	A	B	C	Total	A	B	C	Total	A	B	C	Total	Total
400	19.4	5.84	4.17	29.41	15.6	6.34	5.40	27.34	18.8	6.03	5.36	30.19	86.94
600	15.0	4.52	8.40	27.92	13.2	5.51	8.54	27.25	14.1	3.07	7.90	25.07	80.24
800	29.0	8.48	9.73	47.21	26.1	9.77	8.09	43.96	19.4	8.34	7.87	35.61	126.78
Total	63.4	18.84	22.30	104.54	54.9	21.62	22.03	98.55	52.3	17.44	21.13	90.87	293.96
TOTAL	120.90	51.28	47.15	219.33	108.0	48.50	45.62	202.12	110.2	47.04	43.49	200.73	622.18

TABLE III - 4

ANALYSIS OF VARIANCE
LOSS ON IGNITION
(PERCENT OF DRY WEIGHT)

Level of Factor			Test			
Test Condition	Temp.	Sample	1	2	3	Total
Open	400	A	21.0	18.2	20.5	59.70
"	400	B	10.9	9.18	10.6	30.68
"	400	C	5.23	5.70	5.78	16.71
"	600	A	18.00	16.90	15.70	50.60
"	600	B	11.90	9.95	8.20	30.05
"	600	C	9.62	8.16	7.94	25.72
"	800	A	18.50	18.00	21.70	58.20
"	800	B	9.64	7.75	10.80	28.19
"	800	C	10.00	9.73	8.64	28.37
Covered	400	A	19.40	15.60	18.80	53.80
"	400	B	5.84	6.34	6.03	18.21
"	400	C	4.17	5.40	5.36	14.93
"	600	A	15.00	13.20	14.10	42.30
"	600	B	4.52	5.51	3.07	13.10
"	600	C	8.40	8.54	7.90	24.84
"	800	A	29.00	26.10	19.40	74.50
"	800	B	8.48	9.77	8.34	26.59
"	800	C	9.73	8.09	7.87	25.67
		TOTAL	219.33	202.12	200.73	622.18

TABLE III - 5

EFFECT OF TEMPERATURE

	400	600	800	Total
Open	107.09	106.37	114.76	328.22
Covered	86.94	80.24	126.78	293.96
	194.03	186.61	241.54	622.18

TABLE III - 6

EFFECT OF SAMPLE CHOICE

	A	B	C	Total
Open	168.50	88.92	70.80	328.22
Covered	170.60	57.90	65.46	293.96
	337.10	146.82	136.26	622.18

TABLE III - 7

EFFECT OF SAMPLE VS. TEMPERATURE

	A	B	C	Total
400	113.50	48.89	31.64	194.03
600	92.90	43.15	50.56	186.61
800	132.70	54.78	54.06	241.54
	339.10	146.82	136.26	622.18

Figure III - 3

Percent Loss vs. Temperature

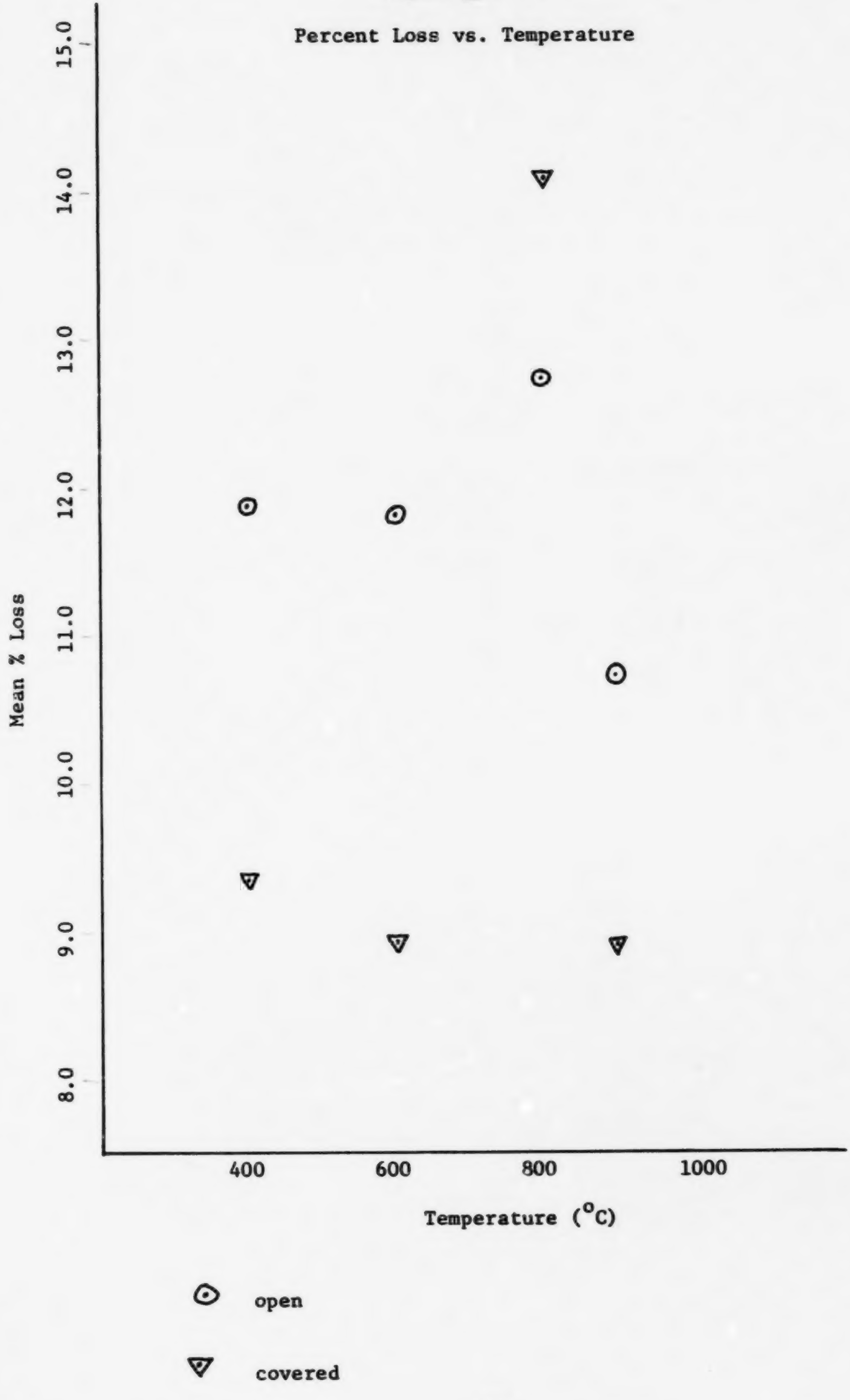


TABLE III - 7 a

ANALYSIS OF VARIANCE

FOUR TEMPERATURE/TWO SAMPLES

			Test			
O - C	Temp.	Sample	1	2	3	Total
Open	400	B	10.90	9.18	10.60	30.68
"	400	C	5.23	5.70	5.78	16.71
"	600	B	11.90	9.95	8.20	30.05
"	600	C	9.62	8.16	7.94	25.72
"	800	B	9.64	7.75	10.80	28.19
"	800	C	10.00	9.73	8.64	28.37
"	900	B	9.44	8.63	9.46	27.53
"	900	C	14.40	11.60	10.90	36.90
Covered	400	B	5.84	6.34	6.03	18.21
"	400	C	4.17	5.40	5.36	14.93
"	600	B	4.52	5.51	3.07	13.10
"	600	C	8.40	8.54	7.90	24.84
"	800	B	8.48	9.77	8.34	26.59
"	800	C	9.73	8.09	7.87	25.69
"	900	B	10.10	8.06	10.40	28.56
"	900	C	10.10	8.15	6.71	24.96
		Total	142.47	130.56	128.00	401.03

TABLE III - 8

SAMPLE VS. TEMPERATURE

		B	C	Total
Temp	400	48.89	31.64	80.53
	600	43.15	50.56	93.71
	800	54.78	54.06	108.84
	900	56.09	61.86	117.95
		202.91	198.12	401.03

TABLE III - 9

TEMPERATURE VS. TREATMENT

	Temp.				
	400	600	800	900	
OC Open	47.39	55.77	56.56	64.43	224.15
Covered	33.14	37.94	52.28	53.52	176.88
	80.53	93.71	108.84	117.95	401.03

TABLE III - 10

SAMPLE VS. TREATMENT

	Sample		
	B	C	Total
OC Open	116.45	107.70	224.15
Covered	86.46	90.42	176.88
	202.91	198.12	401.03

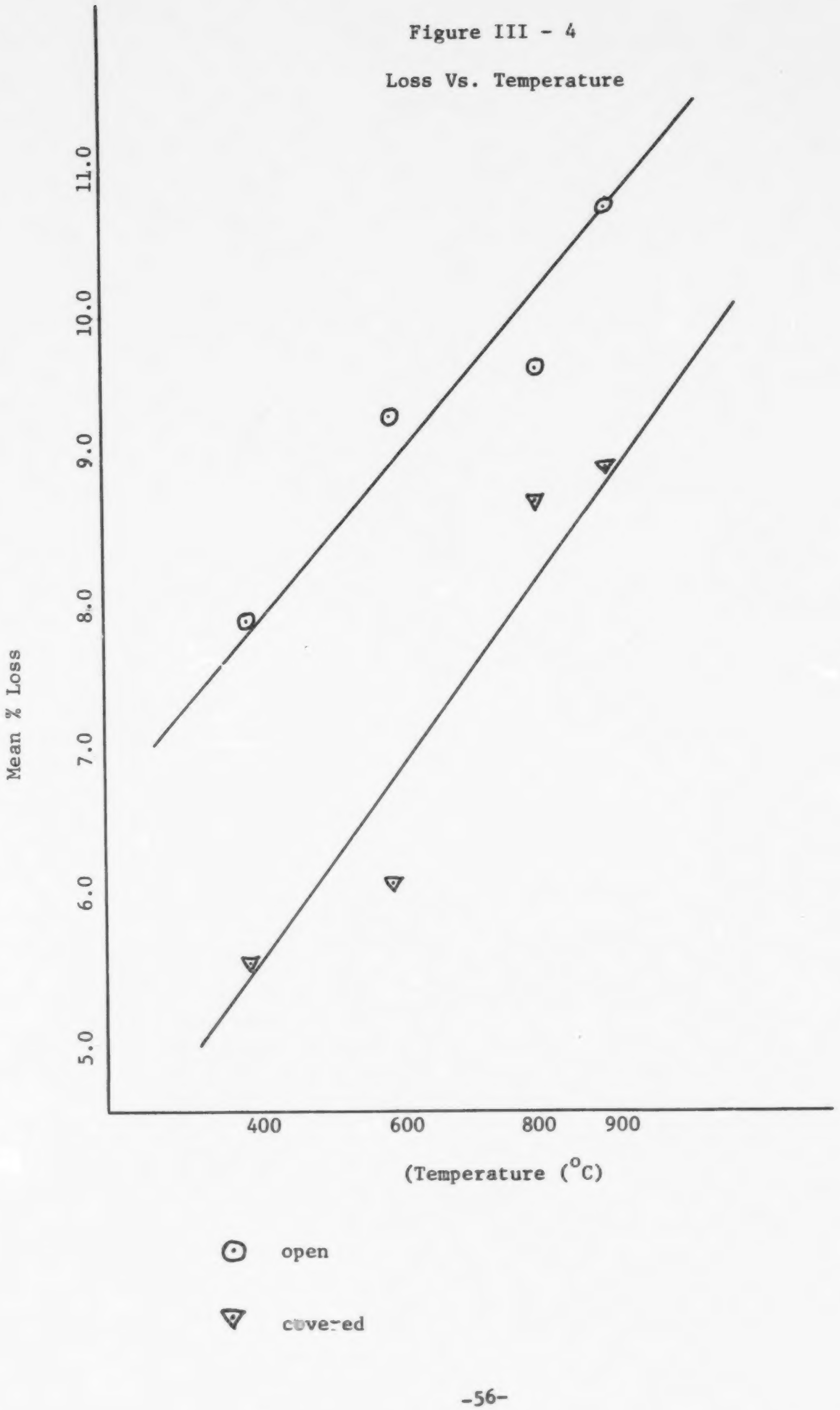


Figure III - 4

Loss Vs. Temperature

The first test involved determining whether the data (the % loss) were uniformally distributed. This was done using the Kolmogrov-Smirnov Test with the hypothesis: % loss is uniformally distributed. This showed that the data were not uniformally distributed and from the results of the other tests, it appears that sample A is completely different from samples B & C. The percentages in sample A were almost twice those of samples B & C.

Nest the Bartlett Test was used to determine if the variances were equal between the factors. The results showed that the variances were not equal for the covered at each temperature, but were equal between the covered and open and between the open at each temperature. The non-uniformity was considered to be not too serious.

The results of the first three factor analysis of variance test were calculated. Testing at the .01 level of significance, it was found that there is a significant difference in the three main effects, and the three two-factor interactions, while the three factor interaction and the replications effect were not significant.

The results of the second test in which sample A was dropped and the 900°C temperature added to B & C, were somewhat different from the first test. At the .01 level of significance, it was found that there is a significant difference in the temperature and O-C effects, but not in the sample effects. Note that in the first test (containing sample A) the sample effects had the greatest significant difference. Furthermore, the temperature - sample interaction was significant, but the other two were not. Finally the three-factor interaction was also significant.

It would appear that sample A has the largest effect, but as for the other differences between the two tests, there are just too many interactions that are significant to tell which has the greatest effect.

To go one step further, it was attempted to determine if there was any significant differences between the covered samples and the temperature, and in the open samples and the temperature. Figure III-3 shows that it is impossible to tell because there are too many interactions. However, when Sample A is neglected (second test), Figure III-4 is drawn. This shows that keeping the sample covered lowers the percent loss in weight, but that this also depends upon the temperature.

Summarizing, it can be said that there is a significant difference in the open and covered effects, but that there are too many interactions to determine the effects of open and temperature, and covered and temperature. To maximize the percent of combustible material in residue or refuse, open crucibles are to be used.

PROTEIN

The Kjeldahl technique is used to determine total organic nitrogen, and the test procedure does not indicate in what form the nitrogen is found. In order to support the Kjeldahl procedure, the amount of protein is determined and a comparison is made with the total organic nitrogen.

Protein is determined by the Biuret technique. This method is specific for protein, and amino acids are excluded from the quantification.

WATER SOLUBLE FRACTION

Amounts and type of water soluble materials in refuse and incinerator residue are of fundamental importance. This is the fraction which can be directly attributed to water quality deterioration and pollution. A comprehensive chemical analysis of this fraction can be undertaken in order to better understand and predict what pollutants are water soluble.

TABLE III - 11

RAW DATA - LOSS ON IGNITION

SAMPLE A

@ 400°C	Dry Sample Weight	Sample Weight after 2 hrs. in oven	Difference	%Loss
open (1)	5.7649	4.5550	1.2099	^{4}21.0%
Cover (2)	5.5908	4.5095	1.0813	^{6}19.4%
open (3)	5.8556	4.7889	1.0667	^{10}18.2%
Cover (4)	5.9881	5.0563	0.9318	^{15}15.6%
open (5)	5.9241	4.7089	1.2152	^{5}20.5%
Cover (6)	5.6350	4.5782	1.0568	^{8}18.8%
@ 600°C				
open (1)	5.5315	4.5367	0.9948	^{12}18.0%
Cover (2)	5.9743	5.0773	.8970	^{16}15.0%
open (3)	5.5149	4.5802	.4347	^{13}16.9%
Cover (4)	5.8956	5.1163	.7793	^{19}13.2%
open (5)	5.9398	5.0068	.9310	^{14}15.7%
Cover (6)	5.7551	4.9408	.8143	^{18}14.1%

@ 800°C	Dry Sample Weight	Sample Wt. after 2 Hrs. in oven	Difference	% Loss
open (1)	5.6554	4.6119	1.0435	^{9}18.5%
Cover (2)	5.5926	3.9746	1.6180	^{1}29.0%
open (3)	5.8976	4.8374	1.0602	^{11}18.0%
Cover (4)	5.7641	4.2615	1.5026	^{2}26.1%
open (5)	5.6083	4.3909	1.2174	^{3}21.7%
Cover (6)	5.9002	4.7557	1.1445	^{7}19.4%

Sample B

@ 400°C	Dry Sample Weight	Sample Wt. Oven after 2 hours	Difference	% Loss
open (1)	8.6312	8.1798	0.4514	^{61}5.23%
Cover (2)	8.4988	8.1450	.3538	^{63}4.17%
open (3)	8.7083	8.2119	.4964	^{57}5.70%
Cover (4)	8.6185	8.1532	.4653	^{59}5.40%
open (5)	8.6793	8.1780	.5013	^{56}5.78%
Cover (6)	8.9629	8.4815	.4814	^{60}5.36%
@600°C				
open (1)	8.6127	7.7834	0.8293	^{34}9.62%
Cover (2)	8.5793	7.8589	.7204	^{42}8.40%
open (3)	8.6428	7.9380	.7048	^{45}8.16%
Cover (4)	8.6398	7.9026	.7372	^{40}8.54%
open (5)	8.5397	7.8624	.6773	^{49}7.94%
Cover (6)	8.6582	7.9739	.6843	^{50}7.90%
@800°C				
open (1)	8.6988	7.8249	0.8739	^{28}10.0%
Cover (2)	8.5520	7.7187	.8333	^{31} 9.73%
open (3)	8.6913	7.8457	.8456	^{32} 9.73%
Cover (4)	8.5247	7.8356	.6891	^{47} 8.09%
open (5)	8.7164	7.9628	.7536	^{38} 8.64%
Cover (6)	8.8932	8.1944	.6988	^{51} 7.87%

Sample B

@800°C	Dry Sample Weight	Sample Wt. After 2 Hrs. in Oven	Difference	% Loss
open (1)	8.6988	7.8249	0.8739	28 10.0%
Cover (2)	8.5520	7.7187	.8333	31 9.73%
open (3)	8.6913	7.8457	.8456	32 9.73%
Cover (4)	8.5247	7.8356	.6891	47 8.09%
open (5)	8.7164	7.9628	.7536	38 8.64%
Cover (6)	8.8932	8.1944	.6988	51 7.87%
@ 900°C				
open (1)	8.5948	7.7842	0.8106	36 9.44%
Cover (2)	8.5891	7.7192	.8699	26 10.1%
open (3)	8.5410	7.8042	.7368	39 8.63%
Cover (4)	8.5857	7.8948	.6909	48 8.06%
open (5)	8.9478	8.1016	.8462	35 9.46%
Cover (6)	8.8408	7.9189	.9219	26 10.4 %

Sample C

@ 400°C	Dry Sample Weight	Sample Wt. after 2 hrs. in oven	Difference	% Loss
open (1)	8.9532	7.9769	0.9763	23 10.9%
Cover (2)	8.8053	8.2908	.5145	55 5.84%
open (3)	8.7133	7.9140	.7993	37 9.18%
Cover (4)	8.8729	8.3103	.5626	54 6.34%
open (5)	8.8707	7.9307	.9400	25 10.6%
Cover (6)	8.8502	8.3163	.5339	55 6.03%
@ 600°C				
open (1)	8.5152	7.4036	1.1116	20 11.9%
Cover (2)	8.5276	8.1420	0.3856	62 4.52%
open (3)	8.5907	7.7361	.8546	29 9.95%
Cover (4)	8.5066	8.0369	.4697	58 5.51%
open (5)	8.6189	7.9119	.7070	44 8.20%
Cover (6)	8.6359	8.3711	.2648	64 3.07%
800°C				
open (1)	8.9114	8.0518	.8596	33 9.64%
Cover (2)	8.7022	7.9641	.7381	44 8.48%
open (3)	8.9081	8.2172	.6909	52 7.75%
Cover (4)	8.7814	7.9243	.8571	30 9.77%
open (5)	8.6278	7.6967	.9311	24 10.8 %
Cover (6)	8.7678	8.0368	.7310	43 8.34%

@900°C

open (1)	8.9092	7.6275	1.2817	^{17}14.4%
Cover (2)	8.6894	7.8095	0.8799	^{27}10.1%
open (3)	8.8086	7.7882	1.0204	^{21}11.6%
Cover (4)	8.6400	7.9355	0.7045	^{46} 8.15%
open (5)	8.5897	7.6523	.9374	^{22}10.9%
Cover (6)	8.7794	8.1903	.5891	^{53} 6.71%

The water soluble fraction is composed of both organic and inorganic compounds. The ash which results from burning foodwaste and paper consists of inorganic materials such as clay fillers. Some of these fillers are soluble in water and contribute to the hardness of the leachate water. Organic water soluble matter is unknown both in quantity and composition. It may also be dependent upon the extent of thermal decomposition which has occured.

Analytical determination of the water soluble fraction is performed by using one of two extraction techniques. Either the soxhlet extraction method, or a filtration technique can be used. The latter method involves stirring at room temperature for several hours followed by filtration. This method is suggested because lower water temperatures are closer to the temperature of rainfall. The soxhlet method uses boiling water for extraction, and this higher water temperature could extract matter which is not soluble at the lower temperature.

ETHER SOLUBLE FRACTION

Material which is soluble in anhydrous diethyl ether has been defined as the lipid content (32). The ether soluble classification contains mostly organic material, but some inorganic compounds may also be present which are soluble in the ether and would therefore be extracted.

Lipids are an important classification of compounds in refuse or residue because of the possibility of their undergoing microbial decomposition. The ether soluble category will not include all the substances which can be classified in the "putrescible group", but most ether soluble compounds are classed as either putrescible or fermentable.

Anhydrous ethyl ether is a volatile and potentially explosive solvent, and if this solvent is used in the extraction extreme caution must be exercised. Comparative studies on the extraction of organic materials using the Soxhlet technique and five different organic solvents showed very little difference in the percent of material removed by each solvent (23). The results which appear in the data section were obtained using petroleum ether as the solvent. Petroleum ether was one of the solvents investigated.

SELECTION OF SOLVENTS

The total procedure involves performance of the Soxhlet extraction with one solvent, drying of the sample, performance with the next successive solvent, and so on until four extractants have been used on the same portion of a given sample. The same procedure is then followed for each of the 3 remaining portions of the original sample but starting with a different solvent for each portion; however, the same order of succession for the solvents is always maintained, so that the order of rotation of solvent usage is always the same.

Therefore, the four different solvents are to be evaluated to determine: (1) which one, used singly, would remove the most organic material and (2) which order of solvents provides the best results (the most organic removal) when the sample is treated with all four solvents in succession.

Data Preparation

Since the raw data, as presented are at best difficult to understand, it was decided to transform it into a more meaningful form. Three transformations were performed, the results of which are shown in Tables III - 12, 13 and 14. The first two concern evaluation of individual extractants while the third is designed to permit evaluation of the orders or successions of extractants.

The data in Table III-12, gives values of relative extraction for the individual solvents used. The values are the percentage of total organic extraction accomplished by the use of the first extractant in each of the orders or sequences; that is, they are the diagonal values for each sample divided by the respective raw totals, as determined from the raw data, and multiplied by 100. It was hoped that analysis of these values would indicate which, if any, of the extractants was relatively more effective, as well as provide an indication of the organic removal due to any one extractant as compared to the sequential application of all four of them. For this and all analysis it was assumed that the portions to which each sequence was applied were relatively homogeneous and selected randomly from a given sample.

Comparison II is simply based on the total extraction for each solvent for each sample. The column totals of the raw data were used for this purpose. Since each extractant is thus considered over each portion of the sample, this analysis does not place such severe reliance on homogenity of the portions.

Finally, Comparison III data was used to evaluate the total extraction due to each sequence or order of extractant application. The values are simply the totals of each row for each portion of the raw data. The extractant heading in Table III-14 indicates the solvent starting the cycle or sequence.

METHOD OF ANALYSIS

It was decided that Analysis of Variance (39) would be used to analyze the data. The treatment - either sequence or single extractant - was considered in the columns while the samples constituted the row variable. Tables III - 12, 13 and 14 are arranged in this manner. Tables III - 15, 16 and 17 give the means and standard deviations of the columns and rows of each Comparison.

The samples used in the analysis of variance were obtained from three different incinerators, all taken at different times. However, from previous studies it is known that samples of incinerator residue, when taken at different times even from the same incinerator, cannot be considered as being homogeneous. Therefore, the samples were considered independently of their origin. Consequently, although not within the scope of this paper, it may be desirable to test for interaction effects between incinerator and sample by using incinerators as raw effects and samples as replications.

The use of analysis of variance presupposes that the populations involved are 1) normally distributed, and 2) of equal, or homogeneous, variance. Normality was tested by using the Kolmogorov - Smirnov test (40) which is especially appropriate here due to the small sample sizes. This test requires the assumption of a continuous distribution which is reasonable in this case. Equality of variance was tested using Bartlett's test; (41) results are shown in Table III-18. In addition, Cochran's test (41) was also used to test homogenity of variance. This test compares the largest variance with the sum of variances to determine whether any one is significantly greater than the others. Since analysis of variance is a fairly "robust" test, strict equality of variance need not be exhibited as long as they are not radically different; Cochran's test attempts to take advantage of this fact.

Finally, Schiffle's method of multiple comparisons (42) was employed to test for relationship and multiple equality of means between various combinations of the treatments (extractants) used. The combinations tested are indicated on the computer output by coefficients; for example, the coefficients .5, .5, - .5, and -.5 indicate that the first two extractants together were compared to the latter two.

RESULTS

The results of the preceeding tests are shown in Table III-18 through Table III-19. The results of Scheffe's multiple comparison were not tabulated since equality of means of every combination of extractants was accepted at the .01 level of significance.

The results of the analysis of variance also indicate that the mean values of the columns (extractants) are equal at the .01 level of significance; this fact held true for each Comparison (I through III) made. Therefore, it appears that there is no significant difference between individual extractants nor between the sequence of solvents used to extract the organic fraction from the residue. No one sequence results in significantly greater extraction; the amounts of organics extracted by individual solvents are not significantly different. However, row differences were quite significant, indicating extensive variation. This might be interpreted as effective blocking and elimination of extraneous variations or as indicating a need for further investigation into sample variations and effects.

Concerning normality, these results are valid since each variable was found to be normally distributed at the .01 level of significance. Since no rejections of normality were made, these results were not tabulated, but can be found in the computer outputs for the Kolmogorov - Smiernov Test.

Equality of variance results are shown in Tables III-18 and III-18B. With the Bartlett test, homogenity of variance was rejected at the .01 level of significance for all rows and columns except the rows of Comparisons II and III. However, Cochran's test indicated that the variances can be considered significantly similar, also at the .01 level, for all columns, while being significantly different for all rows. Therefore, it must be emphasized that the results of the analysis of variance *may* be limited in sensitivity and accuracy.

CONCLUSIONS

As has been mentioned there are significant differences between the samples in all comparisons. Furthermore, no significant difference was found between individual extractants considered by themselves. Neither was there any significant differences between the sequence of extractants used and the amount of organic extraction.

Since individual extractants were found, to be equally effective, an estimate was made of the percentage extraction by any individual solvent as compared to extraction by the complete sequence of extractants. This was done by constructing a confidence interval at the .01 level using the full results of Table III-12. Since normality is satisfied for the extraction percentages in this table (per Kolmogorov - Smiernov), the students - distribution can be used. Consequently, using a grand mean of 81.64 and standard deviation of 15.85 and $n = 36$, the .01 confidence interval for the percent of total removable organics extracted by an individual solvent was found to be $74.44 < r < 88.84$. It would seem, therefore, that the use of a single extractant would be justifiable if only an approximation of extractable organics is required.

In conclusion, two suggestions might be made regarding the experimental procedure involved in obtaining raw data. One is that the selection of the sequence to be applied to each one of the four portions of a sample should be made randomly rather than in the order of initiating the sequence with benzene always on the first portion, carbon tetrachloride on the second portion, etc. This would serve to add validity to the analysis of variance results. The second suggestion is that the four portions to be used from each sample be selected from the sample in a more

TABLE III - 12

COMPARISON I DATA

PERCENT SOLUBLE IN SOLVENT

	Extractant				
Sample	Benzene	Carbon Tetrachloride	Chloroform	Pet Ether	Total
1	62.62	75.32	90.49	67.87	296.33
2	93.05	79.73	87.25	77.72	337.75
3	91.70	85.91	82.33	91.58	351.52
4	83.22	74.42	65.58	72.66	295.88
5	79.52	83.82	81.64	73.15	318.13
6	96.59	95.65	93.88	100.00	386.12
7	98.56	91.97	81.90	93.75	366.18
8	100.00	100.00	79.54	88.89	368.43
9	46.67	52.78	27.59	91.67	218.71
Total	751.96	739.60	690.20	757.29	2939.05

TABLE III - 13

COMPARISON II DATA

PERCENT SOLUBLE BY SOLVENT

Sample	Extractant				Total
	Benzene	Carbon Tetrachloride	Chloroform	Pet Ether	
1	4.85	6.90	11.99	7.14	30.88
2	10.62	10.13	9.64	9.84	40.23
3	8.81	5.42	3.23	7.22	24.68
4	1.70	1.25	1.32	1.44	5.71
5	2.10	2.12	1.29	1.39	6.90
6	.95	.88	.93	.99	3.75
7	1.41	1.37	.99	1.43	5.20
8	.49	.62	.35	.41	1.87
9	.38	.44	.13	1.23	2.18
Total	31.31	29.13	29.87	31.09	121.40

TABLE III - 14

COMPARISON III DATA

PERCENT SOLUBLE BY SOLVENT

	Extractant				
Sample	Benzene	Carbon Tetrachloride	Chloroform	Pet Ether	Total
1	4.90	6.24	10.62	9.12	30.88
2	9.93	10.41	9.88	10.01	40.23
3	8.92	5.40	3.00	7.36	24.68
4	1.49	1.29	1.54	1.39	5.71
5	2.10	1.73	1.58	1.49	6.90
6	.88	.92	.98	.97	3.75
7	1.39	1.37	1.16	1.28	5.20
8	.44	.54	.44	.45	1.87
9	.45	.36	.29	1.08	2.18

TABLE III - 15

MEANS AND STANDARD DEVIATIONS OF COMPARISON I

		Mean	Standard Deviation
Column	1	83.55	18.15
(Population)	2	82.18	14.09
(N = 9)	3	76.69	20.07
	4	84.14	11.39
	1	74.08	12.11
	2	84.44	7.06
	3	87.88	4.58
Row	4	73.97	7.25
(Sample)	5	79.53	4.60
(N = 4)	6	96.53	2.57
	7	91.55	7.01
	8	92.11	9.88
	9	54.68	26.89

TABLE III - 16

MEANS AND STANDARD DEVIATIONS OF COMPARISON II

		Mean	Standard Deviation
column	1	3.48	3.80
(Population)	2	3.24	3.44
(N = 9)	3	3.32	4.38
	4	3.54	3.56
	1	7.72	3.03
	2	10.06	.43
	3	6.17	2.40
Row	4	1.43	.20
(Sample)	5	1.73	.45
(N = 4)	6	.94	.05
	7	1.30	.21
	8	.47	.12
	9	.55	.48

TABLE III - 17

MEANS AND STANDARD DEVIATION OF COMPARISON III

		Mean	Standard Deviation
	1	3.39	3.68
column	2	3.14	3.46
(Population)	3	3.28	4.03
(N = 9)	4	3.68	3.93
	1	7.72	2.61
Row	2	10.06	.24
Sample	3	6.17	2.56
(N = 4)	4	1.43	.11
	5	1.73	.27
	6	.94	.05
	7	1.30	.10
	8	.47	.05
	9	.55	.36

TABLE III - 18

EQUALITY OF VARIANCE BARTLETT'S TEST

	Comparison		
	I	II	III
Columns	*	*	*
Rows	*	-	-

TABLE III - 18B

EQUALITY OF VARIANCE COCHRAN'S TEST

	Comparison		
	I	II	III
Columns	-	-	-
Rows	*	*	*

- accept equality of variance at .01 significance level

* reject equals (etc.)

TABLE III - 19

ANALYSIS OF VARIANCE RESULTS

	Comparison		
	I	II	III
Equality of Means for:			
Columns	-	-	-
Rows	*	*	*

- accept equality of means at .01 significance level

* reject equality (etc.)

randomized manner. Although the present system of taking small portions from a large sample is relatively random in nature, operator bias could be eliminated and a more homogeneous mix obtained if the sample were stirred and shaken before each portion was withdrawn.

IRON

The concentration of iron in refuse or residue is important for several reasons: metallic iron in refuse undergoes partial oxidation during combustion (20) and iron oxides may be soluble in water, thereby causing potential water pollution. When refuse or residue is landfilled the iron will continue to oxidize until the reaction is complete. Not all of the oxidation stages of iron are soluble in water, and only the soluble oxides can be leached into the ground water or surface streams by rainfall.

Visual observations of refuse and incinerator residue indicate that substantial quantities of iron metal are found in both. Development of analytical procedures for iron involved several considerations: the method should be simple and fast, and yet the method should be substantially free of interference from the organic fraction or other metals which are present. Appendix A lists three methods which were used for the determination of iron: a polarographic method, a colorimetric method and an atomic absorption technique. Atomic absorption is recommended as the method which best meets the afore mentioned considerations.

In selecting a method, accuracy and precision as well as time are the most important consideration. For the three methods given in the appendix, each required the use of an analytical instrument. If instrument stability is a factor, visible spectrophotometers are the most stable and reliable tools with which to work. For the polarographic technique, several different methods can be used, but the choice was narrowed to two, before final selection. A series of comparisons was made to determine the better of the two polarographic methods.

To accomplish this, a synthetic refuse sample, whose iron content was known, was prepared and tested by the two methods. The major difference in these two methods revolved about the digestion procedure, one uses sulfuric and the other uses hydrochloric acid. The results of analysis and the statistical treatment of the data are given in Table III-20. The true percent of iron in the synthetic samples was 4.5.

Statistical treatment of the data in Table III-20 can be undertaken using standard techniques. The sample variance for sulfuric acid digestion is 0.0801 and for hydrochloric acid is 0.6991. If a null hypothesis stating that the mean of (X - 4.5) is zero is chosen, then the data can be analyzed using the standard student t test. At a level of significance equal to 0.1, $^{t}0.1 = 7.638$ Values of t for each case are: 1.96 for sulfuric digestion and -1.01 for hydrochloric. Based on this value the hypothesis of sulfuric acid digestion is rejected and digestion in hydrochloric acid is chosen.

To compare the colorimetric method with the hydrochloric acid Polarographic Method a similar experiment was developed. A standard solution of ferrous ammonium sulfate was prepared having an iron concentration of 12.14×10^{-4} grams per ml. This solution was analyzed by the two methods. Results of this series of test are given in Table III-21.

The Polarographic results were consistently higher than the Colorimetric, and the colorimetric results were consistently higher than the actual. Hence, the two sample student t test was used to see if there was actually a significant difference between the two sample

TABLE III - 20

DETERMINATION OF IRON

POLAROGRAPHIC METHODS

COMPARISON OF DIGESTION PROCEDURES

PERCENT BY SAMPLE DRY WEIGHT

Sample Number	Sulfuric Acid (Mean)	Sulfuric Acid (Mean - 4.5)	Hydrochloric Acid (Mean)	Hydrochloric Acid (Mean 4.5)
1	4.65	0.15	4.12	-0.38
2	5.11	0.61	4.53	0.03
3	4.89	0.39	4.78	0.28
4	4.46	-0.04	3.66	-1.84

(x - 4.5) = 0.28
average

(x - 4.5) = 0.48
average

TABLE III - 21

COMPARISON OF IRON TECHNIQUES

POLAROGRAPHIC - COLORIMETRIC

Sample #	Colorimetric g Fe/l x 10^{-4}	Polarographic g Fe/l x 10^{-4}
1	12.3	13.8
2	12.6	13.5
3	12.3	13.5
4	12.6	13.8
5	12.8	13.7

results. A significant difference infers that the colorimetric method is the better technique.

Sample NO	$(X_p - X_{c_c})$
1	1.5
2	0.9
3	1.2
4	1.2
5	0.9
SUM	5.7

Results are that the actual t is greater than 5 cut, hence there is a significant difference and the colorimetric method can be used.

It was further believed that the oxidation state of iron might have an effect on the choice of method. Therefore, another experiement was developed using variable concentrations of ferric ammonium sulfate. The results are given in Table III - 22. For statistical analysis the Student t ($u_1 = 0$) was 0.364 for the Coloremetric method and 1.787 for the Polarographic technique. It can be seen from the results, at a level of significance of 0.1 ($t_{crit.} = 1.533$), there is a significant difference between the values obtained using the Polarographic method. Therefore, this method is rejected as a reliable technique and the colorimetric method becomes the preferred choice based solely upon the statistical evaluation.

During this analysis it was observed that there appeared to be a relationship between the known Iron concentration and the difference between the Polarographic values and the known values. If this statement is true, the polarographic method can be used with the results being converted to true values.

To determine this relationship, the method of least square was used

TABLE III - 22

COMPARISON OF IRON DETERMINATIONS

EFFECT OF CONCENTRATION

(1) Sample Number	(2) Conc. Fe gm/l x 10^{-4}	(3) Iron (Color) gm/l x 10^{-4}	(4) Difference (3-2)	(5) Iron(Polar) gm/l x 10^{-4}	(6) Difference (5 - 2)
1	1.343	1.30	-0.043	1.26	-0.83
2	6.008	6.10	0.092	7.10	1.092
3	11.920	12.10	0.180	14.20	2.280
4	17.900	18.00	0.100	20.90	3.000
5	25.610	28.40	-0.210	32.00	3.890

$\overline{X} = 0.0238$ $\overline{X} = 1.936$

to find the equation of the regression curve. In the equation (X) is the known value of Iron concentration and Y is the measured value. Using the normal equations for least squares,

$$\Sigma Y = aN + b \Sigma X$$
$$\Sigma XY = a \Sigma X + b \Sigma X^{e}$$

solving simultaneously.

(1) $150.34 = a(10)+b\ (131.66)$
(2) $3001.86 = a(131.66) + b\ (2630.82)$

(1) x 13.166
(1) $1979.38 = 131.66a + 1733.44\ b$
(2) $3001.86 = 131.66a + 2630,82$

(1-2) $- 1022.48 = 897.38b$

$b = 1.139$
substituting into (1)

$150.34 = 10a + 149.96$
$a = .038$

The equation of the regression curve would be

$$Y = .038 + 1.139\ X$$

To determine whether a & b are significantly different the t statistic was used

for a. $$t = \frac{a - \alpha}{Se} \sqrt{\frac{n\ Sxx}{Sxx + (n\bar{x})^{2}}}$$

for b $$t = \frac{b - \beta}{Se} \frac{\sqrt{Sxx}}{n}$$

A null hypothesis ($t_{crit.} = 1.397$) was used to check the coefficients of the regression equation. For the intercept value (a) the t value is 0.178 and the null hypothesis can't be rejected. The resulting equation for the polarographic determination of iron is $Y = 1.139X$.

Similar test for the slope of the equation (b) indicated that the hypothesis be rejected. This finding fortifies the contention that there is a difference between the actual concentration and polarographically determined concentration.

The final equation is: $Y = 1.139\ X$

A more useful form of the equation is: $X = 1878\ Y$

In this form the value measured by the polarographic method (Y) could be multiplied by (0.878) to obtain the actual value.

It appears that the colorimetric method gives the more reliable results and therefore is the method chosen for use in this study. However, other factors must be considered before the final decision. Incinerator residue contains many impurities such as unburned organic matter and heavy metal ions, which might effect the absolute determination.

Both methods can be used, but the colorimetric method is the preferred technique. The polarographic method can also be used but each determination requires the use of individual calibration curves. The need to obtain these curves means a greater time per analysis.

A separate study was undertaken to determine if a relationship between the amount of organic material in residue and the percentage of iron in the sample exists. Also, it was hoped to determine whether the organic matter affected the two analytical methods.

Results of determinations of actual residue samples were used. Table III-23 shows the percentage of volatile matter, used as an indicator of organic matter, and the percentage of Iron, determined by the colorimetric method.

This value does not exceed $Z_{0.005} = 2.58$, it is concluded that there is no linear relationship between the amount of volatile matter and the percentage of iron. However, this does not mean that there is no relationship. Also, this does not mean that there is no relationship between the amount of organic matter in a sample and the percentage of iron. Detailed experiments beyond the scope of this project are needed to find such a relationship.

Also, this does not mean that there is no relationship between the amount of organic matter in a sample and the percentage of iron. Detailed experiments beyond the scope of this project are needed to find such a relationship.

HEATING VALUE

As one reads reports and proceedings related to solid waste, a reference to "heating value" or "calorific value" is often made. These references are general, and include such qualitative statements as "the calorific value of refuse is about 5000 Btu per pound", or "European refuse has a much lower heating value than American waste". The heating value of refuse is a function of the individual components and will vary according to the proportions of the individual components.

It can be predicted that the calorific value of refuse will be variable and reflect day to day variation in composition. It is difficult to quantify the variance of heating values since the calorific value of refuse has not been determined except as the weighted average of individual heating values (18).

The general classification of solid waste includes not only solid material, but also semi-solid and selected liquid wastes. Because of the presence of the semi-solid and liquid wastes, the determination of the heating value on separated components is somewhat unreliable and

TABLE III - 23

VOLATILE MATTER VS. IRON

Percent Volatile (x)	Iron Percent (y)	X^2	Y^2	XY
48.03	.5	2,306.88	.25	24.02
54.01	.53	2,917.08	.28	28.63
53.36	.87	2,847.29	.76	46.42
47.97	.83	2,301.12	.69	50.19
49.69	1.01	2,469.10	1.02	19.59
10.31	1.90	106.30	3.61	36.70
15.29	2.40	233.78	5.76	37.34
15.56	2.40	242.11	5.76	31.49
19.68	1.60	387.30	2.56	36.63
14.65	2.50	214.62	6.25	67.66
32.22	2.10	1,038.13	4.41	67.66
30.31	2.10	918.70	4.41	63.65
30.49	1.70	929.64	2.89	51.83
22.90	1.90	524.41	3.61	43.51
28.56	1.80	815.67	3.64	51.41
1.86	20.10	3.46	404.01	37.39
2.72	24.70	7.40	610.09	67.18
4.37	23.50	19.10	552.25	102.70
3.77	27.20	14.21	739.84	102.54
2.56	21.90	6.55	479.61	56.06
4.32	3.92	18.66	15.37	16.93
8.58	4.26	73.62	18.15	36.55
7.74	3.88	59.91	15.05	30.03
6.19	3.85	38.31	14.82	23.83
8.17	3.77	66.75	14.21	30.80
11.92	5.78	142.09	33.41	68.89
15.43	7.94	238.09	63.04	122.51
13.90	23.40	193.21	547.56	325.26
13.64	13.80	186.05	190.44	188.23
14.26	12.90	203.35	166.41	183.95
12.71	25.20	161.54	635.04	320.29
10.01	14.10	100.20	198.81	141.14
10.50	13.70	110.25	187.69	143.85
9.39	16.70	88.17	278.89	156.89
7.15	14.20	51.12	201.64	101.53
4.22	13.00	17.81	169.00	54.86
4.55	14.20	20.70	201.64	64.61
6.86	15.30	47.06	234.09	104.96

4.96	13.10	24.60	171.60	64.98
12.51	12.90	156.50	166.41	161.38
11.02	13.00	121.44	169.00	143.26
11.56	13.40	133.63	179.56	154.90
13.73	12.60	188.51	158.76	172.99
9.51	14.60	90.44	213.16	138.85
19.29	30.90	372.10	954.81	596.06
18.18	34.00	330.51	1,156.00	618.12
12.02	15.40	144.48	237.16	185.11
12.30	16.10	151.29	259.21	198.03
16.00	12.60	256.00	158.76	201.60
8.97	8.24	77.26	67.90	72.43
6.91	7.55	47.75	57.00	52.17
7.58	11.70	57.46	136.89	88.68
8.48	13.10	71.91	171.61	111.09
5.97	5.38	35.64	28.94	32.16
7.55	2.84	57.00	8.07	21.44
7.47	2.38	55.80	5.66	17.78
6.85	2.22	46.92	4.93	15.21
8.42	2.46	170.89	6.05	20.71
9.26	3.29	85.75	10.82	30.47
8.94	9.17	79.92	84.09	81.98
8.15	8.36	66.42	69.89	68.13
7.39	8.36	54.61	69.89	61.78
9.51	9.18	90.44	84.27	87.30
7.77	10.30	60.37	106.09	80.03
917.97	644.57	23,047.42	10,753.11	6,546.60

The correlation coefficient (y) was equal to 0.427 and the z value for the null hypothesis (=o) was 1.92.

difficult to perform.

The procedure of separating refuse into its components used by Kaiser (19) consists of separation of the waste into categories (Table II - 1) and to determine the heating value of each category. Many smaller samples (five to ten cubic feet) or one large sample (one to three cubic yards) must be separated. The time required for hand separation of the components is very long. Also, it is impossible to manually separate the liquid and semi-solid constituents. The separating procedure is not applicable to incinerator residue, since visual character of most of the components has been destroyed.

An alternate approach to the determination of heating value, that can be used for both refuse and residue, is to reduce the particle size of all refuse components. By mixing the pulverized sample the heating value can be estimated by using an aliquot of the large sample. The grinding technique has been applied to other solid fuels (27).

The heating value of refuse is used to predict the heat released during combustion. Because empirical relationships between heating value and the ultimate analysis have not been developed for refuse, heating value is the only valid method for calculation of the heat released during combustion.

Determination of heating value for solid materials is accomplished by combustion in a constant volume bomb with the heat released during the exothermic reaction absorbed in a water bath. Two common oxidants are used in the bombs; hydrogen peroxide and oxygen.

The peroxide bomb method is able to take a larger sample size while the accuracy of the oxygen bomb is better than the peroxide bomb. The time required to perform an analysis using the peroxide bomb is longer than for the oxygen bomb because of the time required for weighing the accelerator and the peroxide. For samples having a low heating value, benzoic acid can be added to raise the heating value of the sample to a level which is easily measured.

Appendix A contains the peroxide bomb method for determining the heating value.

PHOSPHORUS

Phosphate is a necessary element for the growth of plant life, and it is one of the constituents normally added to soils when fertilizers are applied. Phosphorus as phosphate along with nitrate has been implicated in eutrophication of water. If refuse or residue is landfilled leaching of phosphorus can cause an undesirable discharge to surface or ground water. Phosphate concentrations of less than one mg/l have been implicated in eutrophication.

The concentration of phosphorus in refuse and residue is expected to be extremely small. Most of the phosphorus in refuse and residue will be bound in organic wastes such as foodwaste, grass, leaves and wood. Detergents and soaps are also a major source of phosphorus where it is used as a builder. Phosphorus was determined as phosphate by the Molybdate Colorimetric Method (5,37).

CARBOHYDRATE

The amount of carbohydrate material in refuse or residue is an indicator of the immediately available food supply which can be assimilated by all levels of animal life. Carbohydrate material can ferment immediately and act as the food source for microbes.

Chemical analyses of the carbohydrate fraction are very difficult because of the many types of carbohydrates. Although cellulose represents the largest percent of carbohydrate in refuse, it is neither soluble in water nor is easily decomposed by microbes. Thus, it is one form of carbohydrate that is not immediately available as a food source. The Anthrone method presented in Appendix A excludes cellulose from the determination of the carbohydrate fraction, thus, only the carbohydrate that can be easily assimilated by animals and plants is reported as carbohydrate.

CHEMICAL DECOMPOSABLE ORGANIC

The amount of organic material which is capable of undergoing oxidation or fermentation is a very important fraction of incinerator residue. In water quality analysis a technique is used to measure the stabilization of organic matter by microbial activity. This technique is referred to as BOD or the Biochemical Oxygen Demand (1).

The BOD test is mostly applicable to aqueous solutions at or near normal ambient temperatures. Since the BOD test is dependent upon biological stabilization of the wastes in the water, it cannot be used where toxic materials are present that will kill the microorganisms. Therefore, industrial waste waters are analyzed using a technique called the Chemical Oxygen Demand (33) which does not rely upon microbial activity.

The Chemical Decomposable Organic test (CDO) is to be used for solid materials and is similar in procedure to the Chemical Oxygen Deman test for water solutions. The CDO test is to quantify compounds that are present and have carbon to carbon bonds. Although the technique as developed by Orsanic (25) was acceptable, the procedure was modified by using several catalysts to include more of the unsaturated organic compounds in the test results. The results of the CDO test are expressed as the weight of oxygen required to oxidize 100 grams of solid material. This carbon is not oxidized in the CDO procedure.

SULFUR

The concentration of sulfur in raw refuse is of value when estimating the amount of sulfur oxides which are emitted to the atmosphere as a result of incinerating refuse.

The percent of sulfur in bituminous and anthracite coal can approach four percent (28). In refuse, however, the percent of sulfur has been reported at less than one-quarter of one percent (20). Therefore, the sulfur content of refuse does not have the critical significance that is attached to the high sulfur content in coal.

Quantitatively determining the percent of sulfur present in refuse is a time consuming task. The classical gravimetric method requires several hours and is subject to many interferences from chloride and nitrate interaction. A modified version of the peroxide sulfur bomb procedure was developed for determining the sulfur concentration in refuse (26).

NITROGEN

Nitrogen in refuse and incinerator residue will determine whether or not the life cycle of insects and animals will be closed. All animal life requires a variety of nitrogen containing compounds such as amino acids and proteins in order to live and complete this cycle.

Determination of nitrogen is complicated by the numerous oxidation states in which it exists. Techniques to quantify the water soluble forms, including nitrate and nitrite, are different from the Kjeldahl method used for total organic nitrogen. Since it is the organic nitrogen which is necessary to carry out life's processes, a modification of the Kjeldahl method was developed to determine the organic nitrogen in refuse and residue.

FREE CARBON AND SILICA

The concentrations of free carbon and silica in incinerator residue or solid waste material are a more detailed breakdown of the biologically inert material. The source of silica is apparent when one looks at refuse or incinerator residue and sees the large quantity of glass which has been discarded. Free carbon is expected to be present only in minute traces in raw refuse, but in residue it is expected that larger quantities will be present. Possible sources of free carbon include the char remaining after pyrolysis and partial combustion.

In order to determine the concentration of free carbon and silica, a procedure is used whereby the sample is digested in aqua regia to dissolve those substances soluble in the acid. After digestion in the aqua regia the material is filtered, and the solids are dried and placed in a muffle furnace. The loss in weight as a result of combustion in the muffle furnace is an estimate of the amount of free carbon which is present. The remaining fraction is called silica, although it is really a conglomerate of insoluble oxides, the largest percentage being silicon oxides.

Table III - 24 is a list of the tests which are suggested for analyzing refuse and incinerator residue. The sixteen suggested parameters will not give a complete characterization of refuse or incinerator residue, but most of the expected problem areas can be isolated and studied by having a knowledge of the elements and fractions which are listed as parameters in this table.

If greater knowledge is necessary than is given by the parameters listed in Table III - 24, it will be necessary to develop more specific individual techniques. The two fractions which are believed capable of providing more detailed data are the water soluble and the ether soluble fractions. It is these two fractions which contain the materials which are biologically degradable, and the compounds which have potential for causing water pollution.

WATER SOLUBLE FRACTION ANALYSES

Table III - 5 is a list of analyses suggested for characterizing the water soluble fraction. This series of suggested tests is headed by pH, which gives a rapid indication of any changes in the water alkalinity. The pH of leachate is quite important if it is being discharged into a surface stream. Large pH differentials between the leach water and the receiving stream can seriously alter the ecological balance of the stream.

Hardness (calcium, sodium, and potassium) is an indicator of the concentration of inorganic salts which are dissolved in water. Hardness of the water dictates when and how much softening is required. Hardness is determined as mg/l $CaCO_3$ and total hardness is also a fraction of the type of anion concentration.

Nitrates and phosphates are of specific concern because these two compounds are classified as water nutrients. Nutrients are objectionable in water because the process of eutrophication accelerates when the nutrients exist together (11). Nitrates and phosphates are considered the two most important nutrients, but other elements can also contribute to the problem. As a result of their established effect on water quality nitrates and phosphates are included in the analyses of the water soluble fraction.

TABLE III - 24

SUGGESTED PARAMETERS FOR CHARACTERIZATION OF SOLID WASTES

1. Carbon
2. Hydrogen
3. Nitrogen (Organic)
4. Phosphate
5. Iron
6. Sulfur
7. Chemically Decomposable Organic
8. Water Soluble
9. Petroleum Ether Soluble
10. Heating Value
11. Ash
12. Combustible
13. Carbohydrate
14. Protein
15. Free Carbon
16. Silica

TABLE III - 25

ANALYSES OF WATER SOLUBLE FRACTION

---

1. pH
2. Alkalinity
3. Hardness
4. Calcium
5. Iron
6. Sulfate
7. Chloride
8. Sodium
9. Potassium
10. COD
11. Nitrate
12. Phosphate
13. Fluoride

Dissolved iron represents one of the more troublesome problems of landfill leachate. The iron is slowly dissolved in the water over several years and usually remains in solution until oxidation of the soluble ferrous compound. Oxidation occurs from the addition of dissolved oxygen from natural aeration or a chemical oxidizing agent such as chlorine from water treatment. When oxidation occurs the iron will precipitate as ferric hydroxide causing undesirable color to be imparted to the stream bed. While the toxicity of iron is not critical in leachate concentrations, dissolved iron is a potential nuisance problem because of color and aesthetics.

The Chemical Oxygen Demand of water is an indication of the amount of carbonaceous material which is present. Chemical Oxygen Demand requires about three hours to perform while the Biochemical Oxygen Demand requires five days. For highly polluted waters such as landfill leachates, the Chemical Oxygen Demand is a more stable procedure.

The last remaining group of water soluble compounds which are included in Table III - 25 are the common negative ions: sulfate, chloride and fluoride. These ions can cause taste and odor problems in water systems, as well as causing interference in many analytical procedures.

Figure III - 3 is the summary sheet of a characterization scheme for incinerator residue or refuse. An analysis of this scheme shows that most of the tests are performed sequentially which facilitates the overall chemical analysis. Figure III - 3 also shows the grinding and sample preparation stages which are required as preparatory work. The figure includes some tests that might be needed under special conditions, but which are not necessary on a routine basis.

The category called "special analysis" is included for specific procedures which do not fit into the analytical scheme at another point.

Examples include separation of the ether soluble fraction by thin layer or gas chromatography.

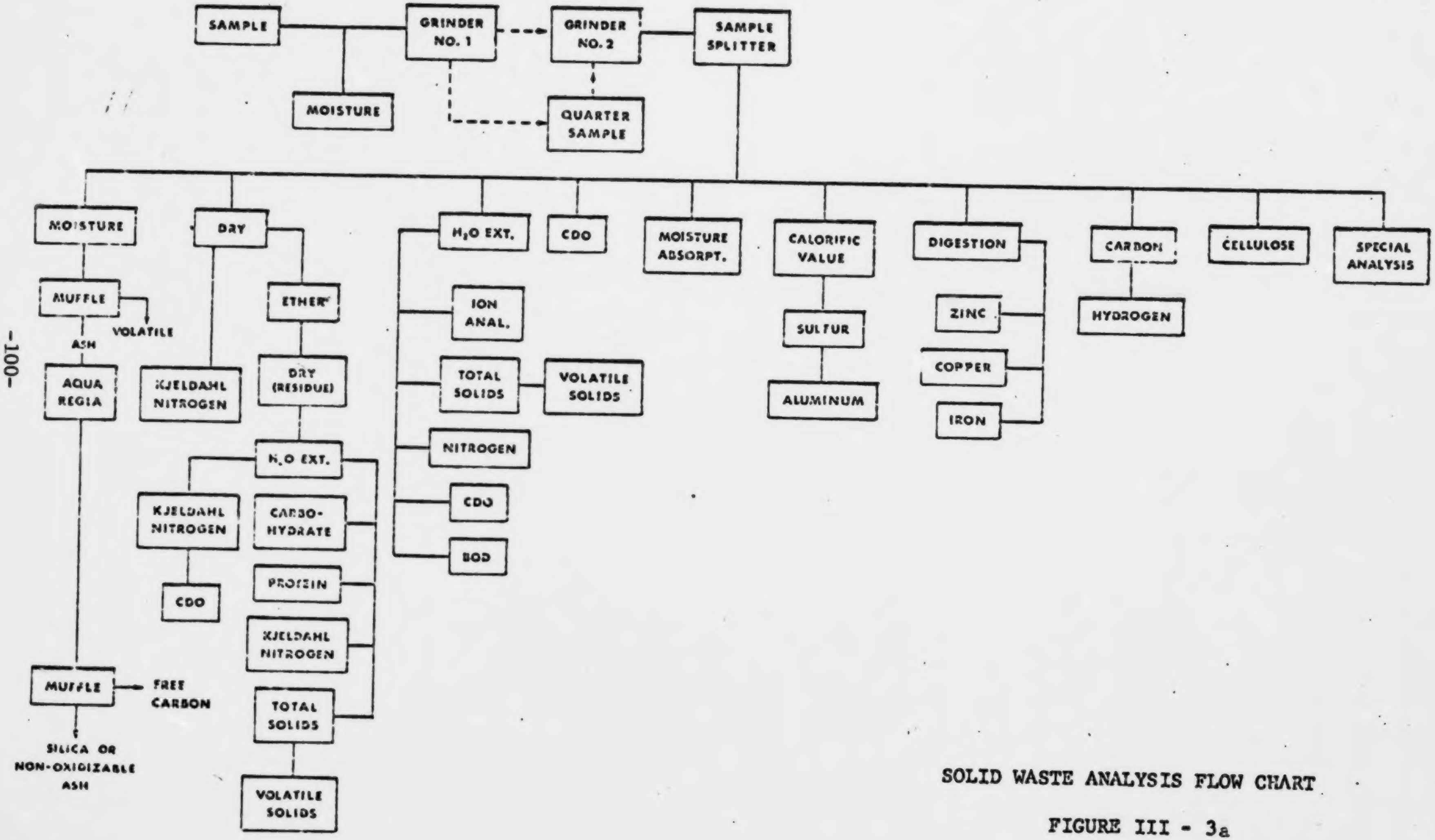
It is expected that the analytical scheme presented is by no means complete, and as more knowledge is gained regarding the chemical nature of residue, other changes in the analytical scheme will result. What has been presented is a characterization scheme which includes public health nuisance conditions, water pollution potential and general solid waste characteristics.

PHYSICAL ANALYSIS

Physical tests are needed to describe the characteristics of refuse and incinerator residue. Of chief concern in the design and operation of materials handling equipment such as compactor trucks and cranes, is the unit weight. The unit weight of refuse is dependent upon three factors: moisture content, refuse composition and the amount of compaction. The unit weight of residue depends upon these factors plus the percent of burnout.

Completeness of combustion (degree of burnout) has a very pronounced effect on the unit weight of residue. If all combustible material has been completely consumed, then the residue will contain only non-combustible materials such as glass and metals, along with the ash remaining after combustion. The glass and metals are the materials of highest density in solid waste, thus, the more complete the burnout, the greater the unit weight of residue is expected to be.

The residue which remains after combustion also consists of inorganic ash having particles smaller than the glass and metal which comprise most of the residue. These particles will pass a Number 4 sieve and help to increase the unit weight by filling the voids between the larger metal and glass. The particle size distribution can be used to predict residue stabilization in the field. When residue is landfilled,


SAMPLE
GRINDER NO. 1
GRINDER NO. 2
SAMPLE SPLITTER
MOISTURE
QUARTER SAMPLE
MOISTURE
MUFFLE
VOLATILE
ASH
AQUA REGIA
MUFFLE
FREE CARBON
SILICA OR NON-OXIDIZABLE ASH
DRY
KJELDAHL NITROGEN
ETHER
DRY (RESIDUE)
H₂O EXT.
KJELDAHL NITROGEN
CDO
CARBO-HYDRATE
PROTEIN
KJELDAHL NITROGEN
TOTAL SOLIDS
VOLATILE SOLIDS
H₂O EXT.
ION ANAL.
TOTAL SOLIDS
VOLATILE SOLIDS
NITROGEN
CDO
BOD
CDO
MOISTURE ABSORPT.
CALORIFIC VALUE
SULFUR
ALUMINUM
DIGESTION
ZINC
COPPER
IRON
CARBON
HYDROGEN
CELLULOSE
SPECIAL ANALYSIS

SOLID WASTE ANALYSIS FLOW CHART

FIGURE III - 3a

the smaller particles can be carried in runoff as suspended material.

In summary it has been shown that a series of methods is necessary to assess the character of refuse or incinerator residue. The research reported in this dissertation attempts to assign characteristics to refuse and residue according to either of the following criteria: effectiveness of burnout or environmental interaction.

Burnout is a parameter used in evaluating the performance of an incinerator, and a technique has been presented for its measurement. The combustible fraction of residue and refuse can be used to predict burnout.

Characterization of solid waste according to potential environmental interaction is possible using one of several criteria. Refuse contains material which is putrescible and fermentable and one result of both of these natural processes is the emanation of odors. Because of the environmental interaction at the land-water interface, determination of the quality and character of water soluble substances is necessary for estimating potential pollution.

The scheme of analysis presented in this section is a general approach used to investigate all facets of environmental interaction. Many of the proposed interactions require specific knowledge of a particular discipline, e.g. entomology, nutrition, and zoology. While the possible existence of these interactions is recognized, the results of this research will be related only to characterizing solid waste and incinerator residue according to water pollution potential and effectiveness of burnout.

IV. DATA EVALUATIONS AND CONCLUSIONS

In Section II the variation in character of incinerator residue and unburned solid waste was acknowledged. It was stated that an incompletely burned incinerator residue could interact with the environment causing undesirable and deleterious impositions upon the environment.

While many of the possible interactions are only hypothetical, a system to measure the parameters involved in these interactions was presented in Section III. Not all of the hypothetical interactions do exist. This dissertation will report on several parameters which have been identified as interacting with the environment.

Parameters associated with important environmental interaction are those which can be directly implicated in real or potential water pollution. Potential pollution of surface and underground water is contingent upon water soluble matter existing in refuse and residue. Table IV - 1 presents average percentages of water soluble material for refuse and two types of residue. This table also lists the percent combustible and percent ether soluble for the three types of samples. All data are given on a moisture free basis.

The three types of material are unburned solid waste, residue from a batch feed, cylindrical furnace (Type I), and residue from a continuous feed, traveling grate furnace (Type II). The refuse which is charged to both incinerator types is similar to the refuse character which is presented in Table IV - 1.

TABLE IV - 1

COMBUSTIBLE AND SOLUBLE FRACTIONS OF SOLID WASTES IN PERCENT OF SAMPLE DRY WEIGHT

(1) Test Procedure	(2) Water Soluble	(3) Ether Soluble	(4) Percent Combustible	(5) Water Soluble	(6) Ether Soluble	(7) Percent Combustible	(8) Water Soluble	(9) Ether Soluble	(10) Percent Combustible
Type of Material	Raw Refuse	Raw Refuse	Raw Refuse	Type I Residue	Type I Residue	Type I Residue	Type II Residue	Type II Residue	Type II Residue
Number of Samples	5	5	5	5	5	5	5	5	5
Number of Analyses	25	25	25	25	24	24	25	25	24
Range	1.27 7.84	1.72 10.00	35.26 82.95	1.36 17.90	0.11 6.30	7.10 43.57	1.01 13.76	0.12 1.66	4.78 17.97
Average	4.82	4.15	58.03	5.62	2.43	19.44	5.48	0.52	9.73
Standard Deviation Within Sample	0.47	0.48	5.36	0.35	0.27	1.79	0.68	0.15	1.18
Standard Deviation Between Samples	1.92	2.62	12.12	2.07	2.34	11.00	5.04	0.28	3.71

Type I residue samples were collected from two incinerators of the same cylindrical design. Type II residue samples were collected from three plants in two municipalities.

Table IV - 1 contains the results of three parameters which are reported as percent of sample dry weight. The range of analytical results reflects the extremes of data values. Number of Samples is the total number of different samples which were analyzed. The Number of Analyses is the total quantity of determinations which were made. In most cases this is five replicate analyses for each sample.

The Standard Deviation Within Samples is a statistical measure of sample heterogenity and analytical error. The Standard Deviation Between Samples represents the day to day variation of the composition of refuse or residue. The Deviation Within Samples should be less than the Deviation Between Samples. If this is not the case, the combined sampling and analytical error is greater than the day to day variation in refuse or residue character.

It can be seen that the average water soluble percent for the three types of material were not very different; the highest percent being 5.62 for type I and the lowest being 4.82 for the unburned refuse. For the ether soluble fraction the unburned refuse had the highest percentage, and the type II residue the lowest. Type II residue also had the lowest percent of combustible matter while the unburned refuse, as expected, had the highest. Thus, there may be a direct relationship between the combustible fraction and the ether soluble fraction.

The combustible percent of residue is dependent upon the degree of burnout; the more complete the combustion of the refuse the greater the concentration of ash. If the relationship between the ether soluble fraction and the percent combustible is direct, then the ether soluble fraction and the percent combustible is direct, then the ether soluble fraction is principally of organic origin.

The relationship which exists between the combustible fractions of refuse and residue as depicted in Figure III - 2 and stated in Equation III - 6 is not valid for all parameters. This relationship is only valid for those parameters which are consumed in the exact ratio that the combustible fraction is consumed.

The percent of burnout as given by Equation III - 6 is:

$$B = (1 - A_oV_f \,/\, A_fV_o) \times 100 \text{ ----------------------III - 6}$$

If the burnout is 100 percent, then V_f is zero and B equals 100. However, it has already been shown that one unit weight of residue $(A_f + V_f)$ resulted from the combustion of (1 / 1 - K) unit weight of refuse. Equation III - 4A shows the combustible fraction relationship between refuse and residue.

$$K = (V_o - A_oV_f \,/\, A_f) \text{------------------------------III - 4A}$$

Equation III - 4A can be viewed as a concentrating factor for refuse and residue. This equation can be used to determine whether the ether or water soluble fractions are consumed in the same ratio as the combustible fraction.

Table IV - 2 investigates the ratio at which the water soluble and ether soluble percentages are consumed in relation to the combustible fraction. The concentrating factor K and computed initial weight of refuse (1 / 1 - K) are presented for the data in Table IV - 1. In all four cases the expected water or ether soluble concentration is less than the actual measured percentage in the refuse. This means that a portion of the water soluble and ether soluble fractions are removed during combustion. The percentages of water soluble fraction which are removed for type I and type II residue are 39.21 and 45.20 respectively. The ether soluble percentages which are removed are higher for both

TABLE IV - 2

RELATIONSHIP BETWEEN PARAMETER CONCENTRATION AND CONCENTRATING EFFECT

(1)	(2) Type I Residue	(3) Type II Residue	(4) Refuse
Percent Water Soluble	5.62	5.48	4.82
Percent Ether Soluble	2.43	0.52	4.15
K (Concentrating Factor	0.479	0.535	----
1 / 1-K	1.92	2.15	----
Expected Water Soluble Percent in Refuse	2.93	2.64	----
Expected Ether Soluble Percent in Refuse	1.27	0.24	----
Water Soluble Removed	1.89	2.18	----
Ether Soluble Removed	2.88	3.91	----
Percent Water Soluble Removed	39.21	45.20	----
Percent Ether Soluble Removed	69.41	94.25	----
Burnout	82.40	92.10	----

types of residue than are the respective water soluble percentages. The percentage of burnout for the two types of residue are 82.4 and 92.1 percent respectively. Neither the water soluble nor the ether soluble percentages removed during combustion are in the same ratio as the combustible matter consumed, except for the type II ether soluble percent. This would seem to follow since the ether soluble percentage is combustible, and at high percentages of burnout the ether soluble percent would also be consumed.

Tables IV - 3, VI - 4 and IV - 5 are analyses of the water soluble fractions for type I residue, type II residue, and unburned solid waste material. The parameters which are reported include pH, Alkalinity, Nitrates, Phosphates, Chloride, Sulfate, Sodium, Potassium and Iron.

The pH of the water soluble fractions are respectively alkaline for type II (9.17), and slightly acid for type I residue and the unburned refuse. The pH range is quite narrow for raw material, less narrow for type II and extremely broad for type I. The broad range of Type I residue (1.7 - 9.0) indicates that type I residue is not of a consistent character. This conclusion can be easily verified by a few visual observations of type I residue.

In Tables IV - 3 to IV - 5, it is seen that the concentrations of sulfate and chloride appear to follow different directions; the chloride being largest in raw refuse and lowest in type II. This would indicate that the chloride concentration in refuse is given off during combustion. Sulfate on the other hand is highest in type II residue and almost identical in type I residue and refuse.

Table IV - 6 summarizes the expected removal of various water soluble components during combustion of refuse. It can be seen that most of

TABLE IV - 3

ANALYSES OF WATER-SOLUBLE FRACTIONS OF TYPE I RESIDUE, IN PERCENT BY DRY WEIGHT SAMPLES

(1) Test Procedure	(2) pH	(3) Alkalinity (as $CaCO_3$)	(4) Nitrates x 10-4	(5) Phosphates x 10-4	(6) Chloride	(7) Sulfate	(8) Sodium	(9) Potassium	(10) Iron x 10-2
Number of Samples	6	6	6	6	6	6	6	6	6
Number of Analyses	6	6	6	6	6	6	6	6	6
Range	1.7 9.0	0.00 0.29	0.0 16.0	4.75 1.19	0.02 0.25	0.002 0.33	0.02 0.12	0.01 0.12	0.08 2.20
Average	6.17	0.12	4.01	2.75	0.12	0.08	0.05	0.04	0.62

TABLE IV - 4

ANALYSES OF WATER-SOLUBLE FRACTIONS OF TYPE II RESIDUE, IN PERCENT BY DRY WEIGHT OF SAMPLES

(1) Test Procedure	(2) pH	(3) Alkalinity (as $CaCO_3$)	(4) Nitrates x 10-4	(5) Phosphates x 10-4	(6) Chloride	(7) Sulfate	(8) Sodium	(9) Potassium	(10) Iron x 10-2
Number of Samples	6	6	6	6	6	6	6	6	6
Number of Analyses	6	6	5	6	6	6	6	6	6
Range	6.9 11.0	0.01 0.45	0.80 9.92	2.08 7.68	0.03 0.14	0.10 0.73	0.01 0.97	0.004 0.14	0.00 3.50
Average	9.17	0.19	3.48	4.42	0.08	0.24	0.20	0.05	1.50

TABLE IV - 5

ANALYSES OF WATER-SOLUBLE FRACTIONS OF RAW REFUSE, IN

PERCENT BY DRY WEIGHT OF SAMPLES

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Test Procedure	pH	Alkalinity (as $CaCO_3$)	Nitrates x 10-4	Phosphates x 10-4	Chloride	Sulfate	Sodium	Potassium	Iron x 10-2
Number of Samples	6	6	6	6	6	6	6	6	6
Number of Analyses	6	6	6	6	6	6	6	6	6
Range	5.60 7.20	0.05 0.32	2.40 16.30	1.92 42.40	0.03 4.30	0.03 0.12	0.02 0.26	0.01 .18	0.13 2.7
Average	6.43	0.17	6.56	10.06	0.77	0.09	0.08	0.07	1.06

TABLE IV - 6

EFFECT OF COMBUSTION ON WATER SOLUBLE PARAMETERS

(1)	(2) Type I Residue	(3) Type II Residue	(4) Unburned Refuse
K (Concentrating Factor)	0.479	0.535	----
1 / 1 - K	1.92	2.15	----
Chloride	0.12	0.08	0.77
Sulfate	0.08	0.24	0.09
Nitrates	4.01	3.48	6.56
Sodium	0.05	0.20	0.08
Expected Chloride in Refuse	0.06	0.04	----
Expected Sulfate in Refuse	0.04	0.11	----
Expected Nitrate in Refuse	2.08	1.62	----
Expected Sodium in Refuse	0.03	0.09	----
Percent Chloride Removed	92.4	94.8	----
Percent Sulfate Removed	55.5	0.0	----
Percent Nitrate Removed	67.3	75.3	----
Percent Sodium Removed	62.5	0.0	----

the chloride is removed from both types of residue. At the opposite extreme no sulfate or sodium is removed from type II residue. For all components except chloride, the percent removal during incineration is less than the percent of burnout (Table IV - 2).

There does appear to be a difference in the water soluble iron content in the three types of material. The greatest concentration of iron is in type II residue, where it is expected that the greatest amount of oxidation has occured because the percent of burnout is greatest.

PROCESS WATER ANALYSES

Data which are presented in Tables IV - 1, 3, 4 and 5 are the maximum concentrations of water soluble material which are present in the three wastes. The data were obtained from analyses performed on the type of waste exactly as it was received. Since these data do represent maximum values, the concentration of each parameter at a given time in leachate and process waters is unknown, but it will be somewhat less than the maximum value. The rates at which the parameter concentrations are released are also unknown.

Table IV - 7 is a compilation of actual water analyses showing the character of quenching water and spray water from a residence chamber, both from a type II residue incincerator.

The chemical character of the samples reported in Table IV - 7 have several parameters which are of definite water quality concern. The chloride and fluoride concentrations are both above the recommended standards for public water supplies. In fact, the fluoride concentration is between four and seven times the maximum allowable concentration.

LANDFILL LEACHING

In order to complete the study of environmental interaction between landfilled residue and the water quality of surface and underground

TABLE IV - 7

PROCESS WATER ANALYSES[a]

(1) Test	(2) Spray Chamber	(3) Spray Chamber	(4) Quench	(5) Quench
pH	7.9	5.5	3.5	6.2
Alkalinity	35	9	0	10
Nitrate	1.50	1.90	2.00	2.00
Phosphate	0.17	0.61	0.39	0.17
Chloride	582	453	567	422
Fluoride	4.50	6.40	4.40	7.80
Calcium	330	220	255	250
Sulfate	338	238	188	300
Sodium	85	63	73	60
Potassium	27.0	14.8	16.7	14.0
Iron	1.55	0.93	5.77	0.50
ABS	1.91	0.10	0.19	0.21

---

[a] All results are expressed in mg/l except pH

waters, it is necessary to study the leachate from an existing landfill. Because field data must be obtained as it is available, control over variables such as temperature, rainfall and degree of landfill compaction cannot be exercised. Two residue landfills were studied, and samples of leachate from each site were taken and analyzed. Because of the lack of control over the variables, the samples taken were only grab samples.

Table IV - 8 lists the results of analyses for a surface stream flowing along one border of a landfill receiving only type II incinerator residue. The landfill is small in areal extent, having a surface area of only about four acres. The depth of the landfill is also rather small and is a maximum of about 30 feet. The stream does not flow directly through the landfill, but rather flows on the ground surface immediately adjacent to the landfill on the downslope side.

As can be discerned from this table, the pH of the stream water increases slightly, and the alkalinity shows a large increase. Calcium and chloride also show a large increase, but sulfate and nitrate decrease. The largest change in results is in the phosphate concentration which increases by almost 300 percent. This large change in phosphate concentration cannot be totally explained, however, most of the other changes in character can result from residue leaching.

At the time of the field observations, the landfill was only in operation about two months, and it is not known what magnitude of changes will occur in the future. If the existing slow rate of leaching continues, no appreciable buildup of undesirable ions will develop.

Table IV - 9 contains four sets of leachate analyses from a residue landfill which was placed in service during July 1964. This landfill represents a unique situation in that the landfill was entirely contained within an abandoned water reservoir. The reservoir was originally

TABLE IV 8

RESIDUE LANDFILL STREAM EFFECT[a]

(1) Test	(2) Upstream	(3) Downstream
pH	7.7	8.0
Alkalinity	185	292
Phosphate	0.45	1.34
Ammonia - N.	0.37	0.59
Nitrate	2.92	0.40
Chloride	72	93
Sulfate	145	117
Hardness	400	400
Copper	0.014	0.062
Calcium	74	83

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[a] All results in mg/l except pH

TABLE IV - 9

RESIDUE LANDFILL LEACHATE[a]

(1) Date Test	(2) 6/67 No. 1	(3) 9/67 No. 2	(4) 2/68 No. 3	(5) 6/68 No. 4
pH	8.9	7.4	7.5	8.1
Alkalinity	4275	3500	4200	4380
Nitrate	0.15	----	16.70	0.50
Phosphate	7.05	10.40	15.21	43.5
Chloride	1280	68	2060	1957
Fluoride	0.50	5.7	4.0	10.0
Calcium	3	23	23	26
Sulfate	4	311	125	232
Sodium	3250	1230	3300	3500
Potassium	463	425	26.2	23.5
Iron	2.16	3.30	3.62	3.77

[a] All results in mg/l except pH

constructed with an impermeable clay lining, and rainfall which is incident upon the landfill surface does not run off, but percolates through the fill material and is trapped within the clay liner. Relief of the hydrostatic pressure buildup in the artifically constructed perched water table is through a leak on the south embankment of the reservoir. When the water table of the landfill is at a high enough elevation, the leachate percolates onto the ground surface. The analyses in Table IV - 9 are the analytical results of leachate samples taken at three month intervals for one year. The results presented in the table start with the oldest sample (Number 1), taken June 1967, and proceed in order to Number 4 which was taken in June 1968.

Several of the parameters are of special concern, notably the steady rise in phosphate, fluoride, and iron concentrations. It is expected that the concentration of iron would increase as oxidation of the metal occurs, however, the sources and reasons for the rise of the other parameters is not apparent. The high concentration of sodium is a perplexing mystery. The water soluble fraction of Table IV -4 did not yield sodium concentrations of this magnitude.

Sodium is of more than passing interest in the concern for water quality. Salinity can be tasted at low levels, i.e. less than 250 mg/l. Microbial populations are affected by sodium, and stream quality can be upset by sodium concentration of this magnitude.

Tables IV - 10, IV - 11, and IV - 12 are a compilation of data for type I residue, type II residue and for refuse. Also, included for each table is a brief statistical treatment of the data. The tables present data on the following parameters: carbon, hydrogen, nitrogen, iron, combustible fraction, chemical decomposable organic (CDO), ether soluble

TABLE IV - 10

CHEMICAL ANALYSES OF TYPE I RESIDUE IN
PERCENT BY DRY WEIGHT OF SAMPLE

(1)	(2) Carbon	(3) Hydrogen	(4) Nitrogen	(5) Ether Soluble	(6) CDO	(7) Heating Value	(8) Water Soluble	(9) Combustible Fraction	(10) Iron
Number of Samples	5	5	3	5	5	5	5	5	5
Number of Analyses	25	25	13	24	15	19	25	24	24
Range	11.0 36.0	0.56 4.54	0.08 0.23	0.11 6.30	0.98 3.61	1229 5311	1.36 17.90	7.10 43.57	1.0 27.77
Average	22.58	2.21	0.18	2.43	2.02	2828	5.62	19.44	8.59
Standard Deviation Within Sample	3.64	0.40	0.02	0.27	0.23	171	0.35	1.79	2.51
Standard Deviation Between Samples	7.00	1.18	0.04	2.34	0.77	1305	2.07	11.00	5.99

TABLE IV - 11

CHEMICAL ANALYSES OF TYPE II RESIDUE IN PERCENT BY DRY WEIGHT SAMPLES

(1)	(2) Carbon	(3) Hydrogen	(4) Nitrogen	(5) Ether Soluble	(6) CDO	(7) Heating Value	(8) Water Soluble	(9) Combustible Fraction	(10) Iron
Number of Samples	5	5	3	5	4	5	5	5	5
Number of Analyses	25	25	15	25	12	15	25	24	25
Range	4.25 18.80	0.15 1.87	0.02 0.66	0.12 1.66	0.37 2.52	929 2582	1.01 13.76	4.78 17.97	2.05 34.16
Average	9.99	0.83	0.12	0.52	1.16	1728	5.48	9.73	18.18
Standard Deviation Within Sample	1.34	0.09	0.08	0.15	0.12	143	0.68	1.18	5.16
Standard Deviation Between Samples	4.11	0.53	0.07	0.28	0.76	463	5.04	3.71	7.93

TABLE IV - 12
CHEMICAL ANALYSES OF RAW REFUSE IN PERCENT BY DRY WEIGHT OF SAMPLE

(1)	(2) Carbon	(3) Hydrogen	(4) Nitrogen	(5) Ether Soluble	(6) CDO	(7) Heating Value	(8) Water Soluble	(9) Combustible Fraction	(10) Iron
Number of Samples	5	5	3	5	3	5	5	5	4
Number of Analyses	23	23	14	25	9	17	28	25	17
Range	21.14 51.92	3.77 6.78	0.07 0.22	1.72 10.00	2.01 4.08	2814 6806	1.27 7.84	35.26 82.95	0.50 17.08
Average	33.91	4.89	0.12	4.15	3.23	5024	4.82	58.03	5.81
Standard Deviation Within Sample	4.62	0.62	0.01	0.48	0.04	425	0.47	5.36	1.84
Standard Deviation Between Samples	3.48	0.43	0.05	2.62	0.83	1030	1.92	12.12	4.78

fraction, water soluble fraction and heating value. Analytical procedures for each parameter are included in Appendix A.

The statistical presentation of the data is mostly self-explanatory. The range is the values of the lower and upper extremes, and the average is the arithmetic mean. The two standard deviations will require a more detailed explanation.

For every sample of refuse or residue between three and five replicate samples were analyzed. The "Standard Deviation Within the Sample" is a combined estimate of the experimental precision and heterogeneous nature of the sample. Since the results of this test are not zero, it is assumed that attempts to homogenize the sample have not been perfected. Thus, the multi-replicate system of analysis is required to obtain an average value for the individual parameters for each sample.

The "Standard Deviation Between Samples" is an indicator of the daily variation in solid waste character for the given parameter. This deviation is a measure of the effect of incinerator operation, as well as of the effect of the refuse charged on residue character. Except in one case the Deviation Between Samples is larger than the Deviation Within Samples. This indicates that the daily variation in residue character is greater than the variation of character within each sample. The single case where the magnitude of the deviations is reversed is in the carbon and hydrogen determination for raw refuse.

It can be seen that the range for each parameter is large. This indicates a large daily variation in character which is supported by the large deviation between samples. A reason for the large range and deviation between samples can be attributed to the fact that samples were randomly collected in order to minimize any sampling bias.

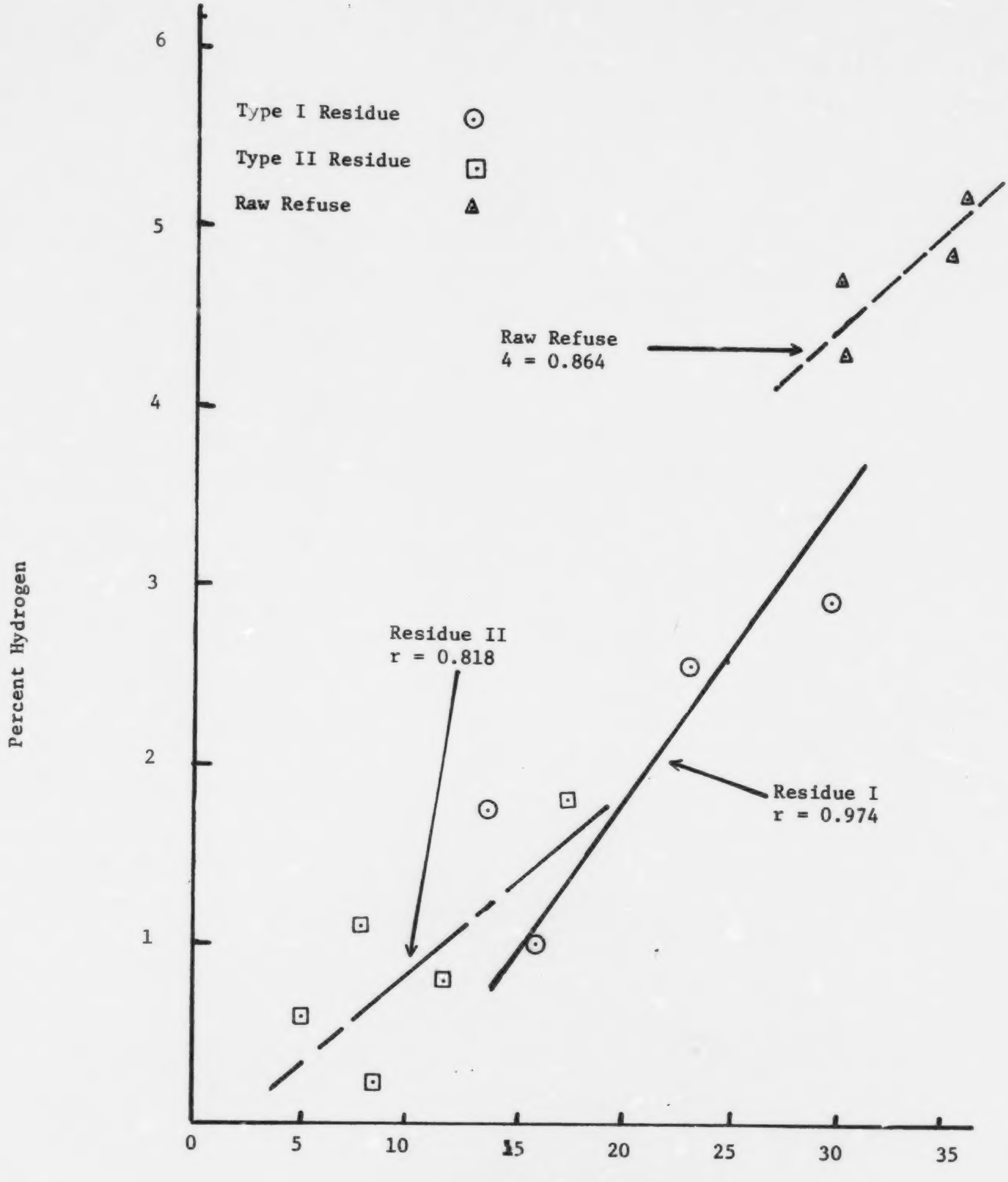
In Table IV - 13 there is listed a summary of linear regression analyses for selected parameter pairings from Tables IV - 10, 11, and 12. The parameters were paired for analysis by employing a priori knowledge of the potential relationships. A regression equation was obtained for each pair of variables and Pearson's correlation coefficient (r) was also determined as an estimate of the equation's reliability. Criteria were developed to estimate probable correlation. A correlation coefficient greater than 0.800 was judged to have positive correlation and less than that value to have no correlation. Correlation was obtained for carbon/hydrogen, percent combustible/heating value, heating value/CDO and CDO/combustible for all three solid waste types. Partial correlation (correlation for at least one type) was obtained for CDO/nitrogen, heating value/carbon, percent combustible/percent ether soluble, and percent ether soluble/nitrogen. No correlation (conclusion zero for all three types of solid waste) was obtained for carbon/nitrogen and ether soluble/CDO. For the paired variables, having at least one positive pairing, curves were plotted using the regression equation. Figures IV - 1 to IV - 7 are those curves.

In Figure IV - 1 are plotted percent hydrogen vs. percent carbon for each residue and refuse. For all three pairings there is probable correlation. The slope of the regression equation is similar in all cases, and it is seen that the percent hydrogen in refuse for any given carbon content is higher than the carbon content of residue. A possible reason for this finding relates to the form of carbon in the different types of waste. Raw refuse is predominantly carbohydrate, while in residue there is some free carbon, the presence of which raises the carbon/hydrogen ratio of the waste.

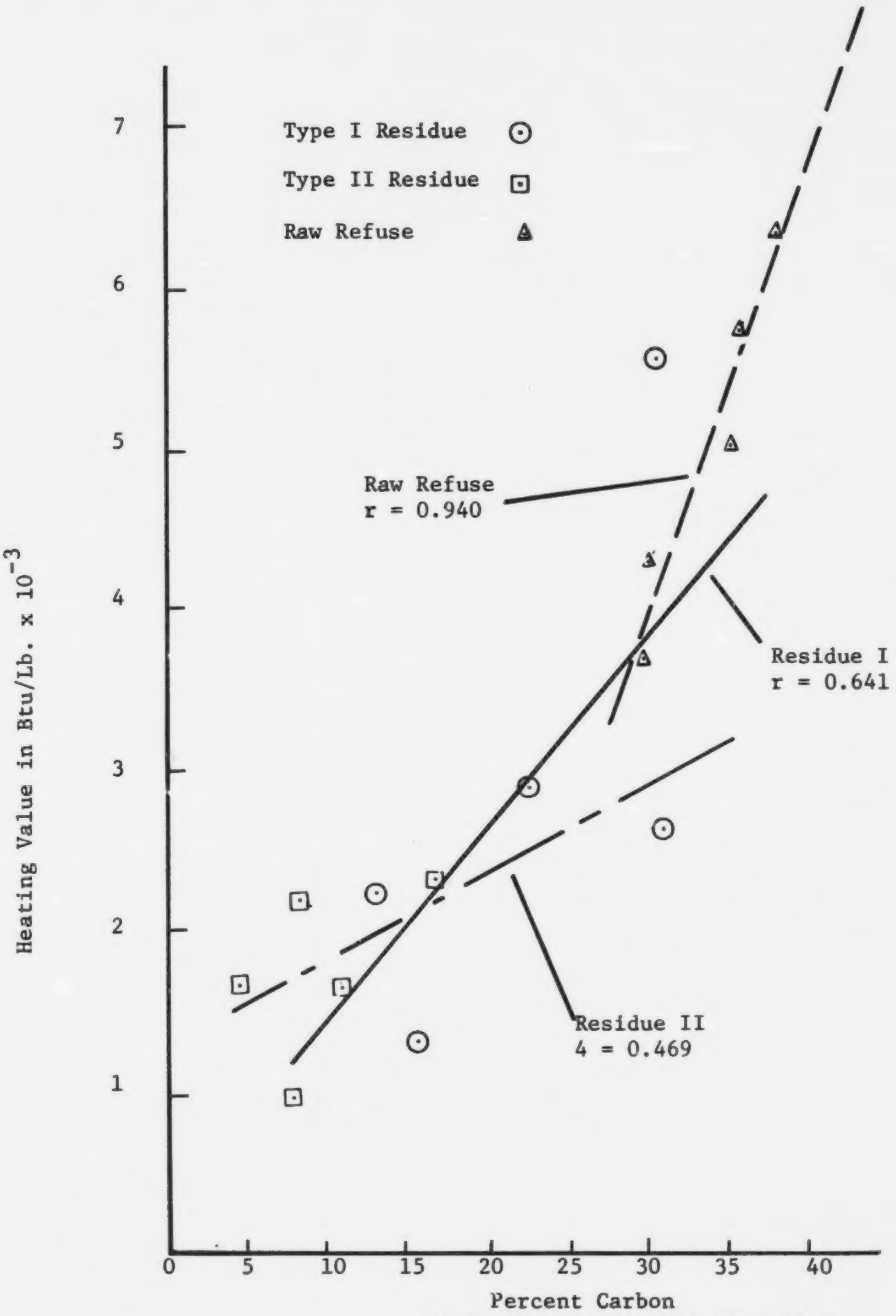
TABLE IV - 13
REGRESSION ANALYSES OF PARAMETERS

Variables	Correlation Coefficient Type II	Conclusion	Correlation Coefficient Type I	Conclusion	Correlation Coefficient Raw Refuse	Conclusion
Carbon - Hydrogen	0.818	+	0.974	+	0.864	+
Carbon - Nitrogen	0.372	0	0.519	0	-0.350	0
CDO - Nitrogen	-0.890	+	0.694	0	-0.981	+
Combustible - Btu	0.866	+	0.982	+	0.910	+
Ether - CDO	0.741	0	0.743	0	0.312	0
Ether - Nitrogen	-0.835	+	----	a	-0.558	0
Btu - Carbon	0.469	0	0.641	0	0.940	+
Btu - CDO	1.000	+	0.940	+	0.910	+
Combustible - Ether	0.889	+	0.570	0	-0.207	0
CDO - Combustible	0.866	+	0.975	+	0.997	+

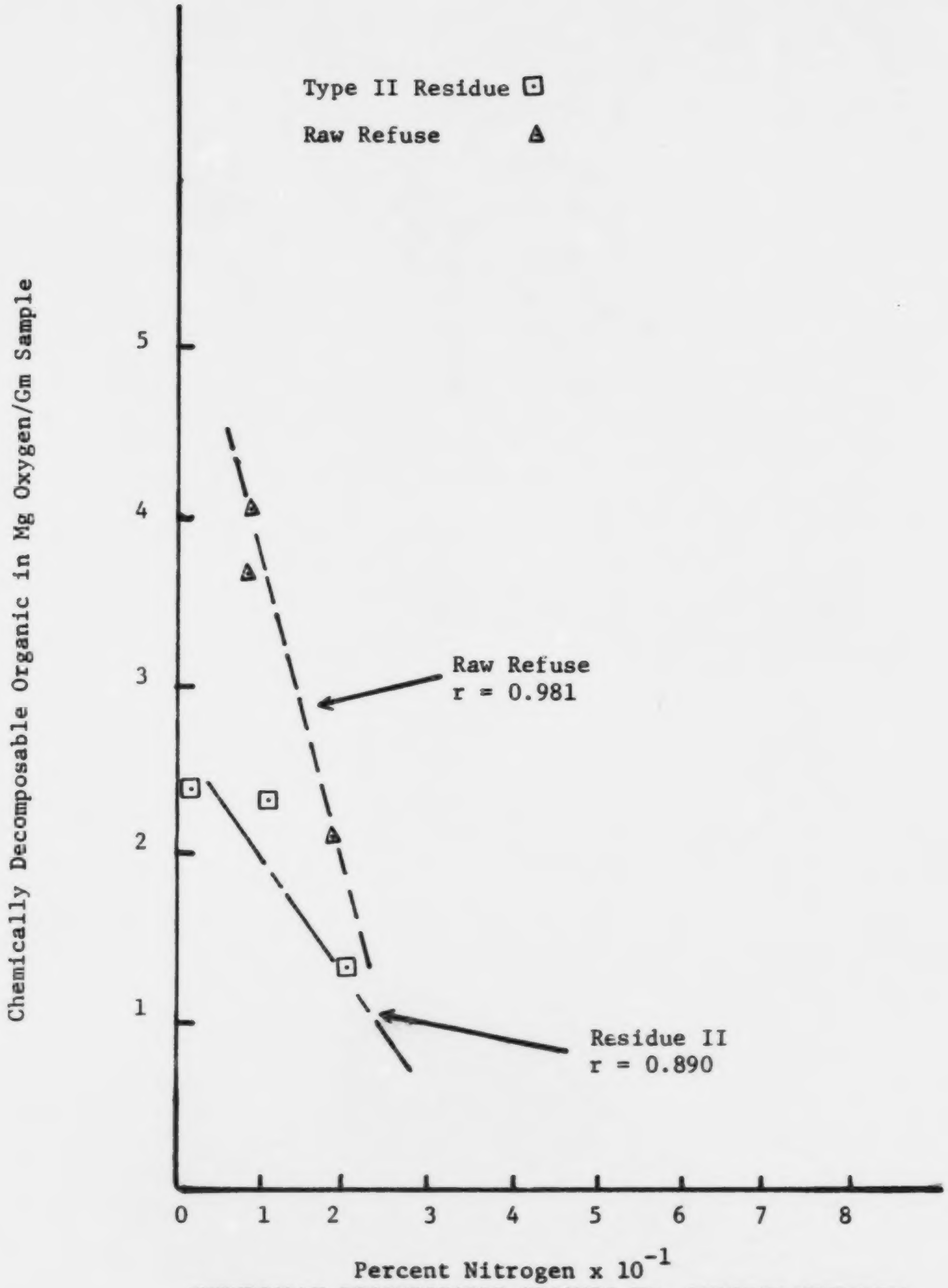
[a] Insufficient data



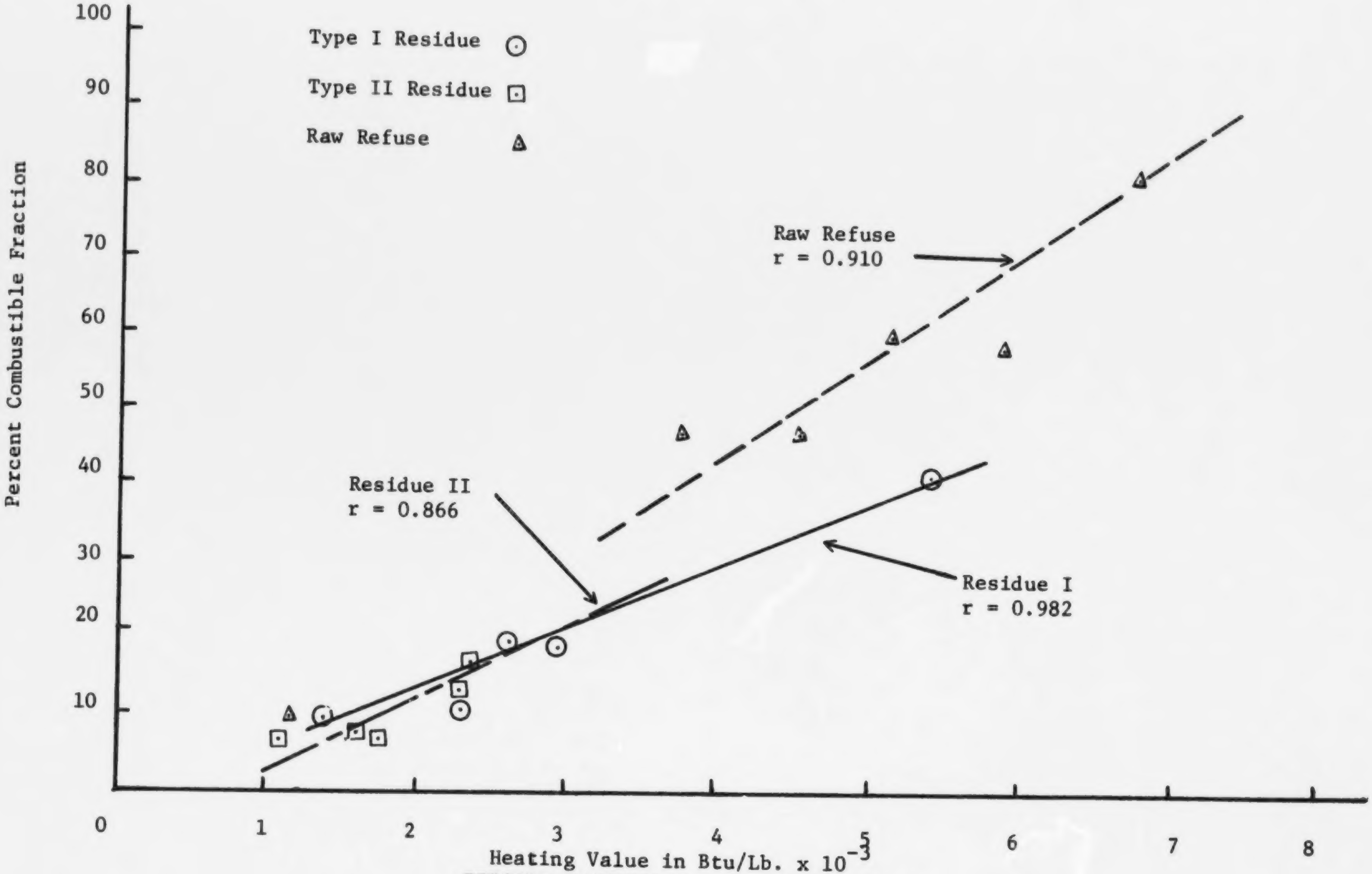
Percent Carbon
PERCENT HYDROGEN VS. PERCENT CARBON
FIGURE IV - 1



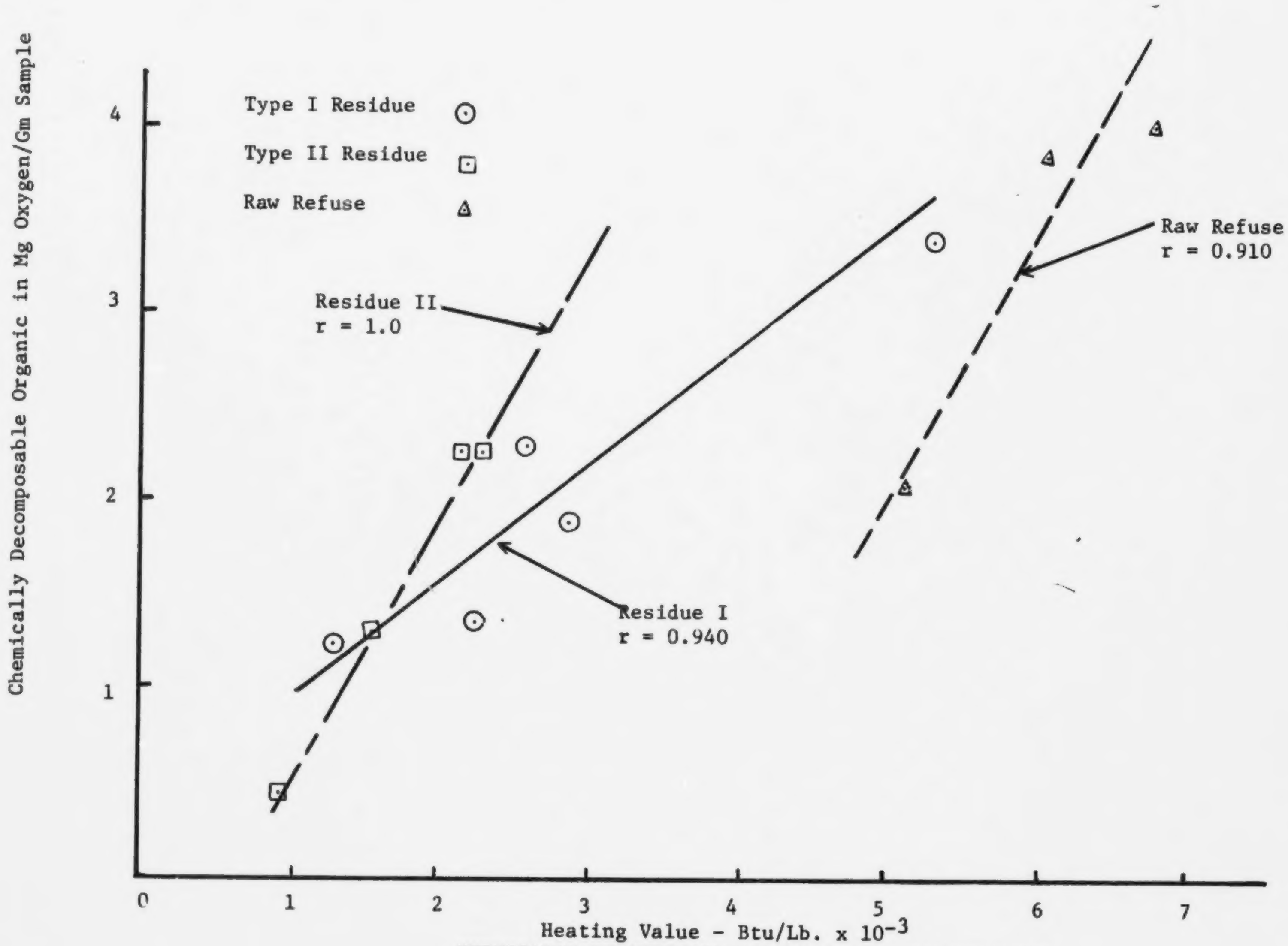
HEATING VALUE VS. PERCENT CARBON
FIGURE IV - 2



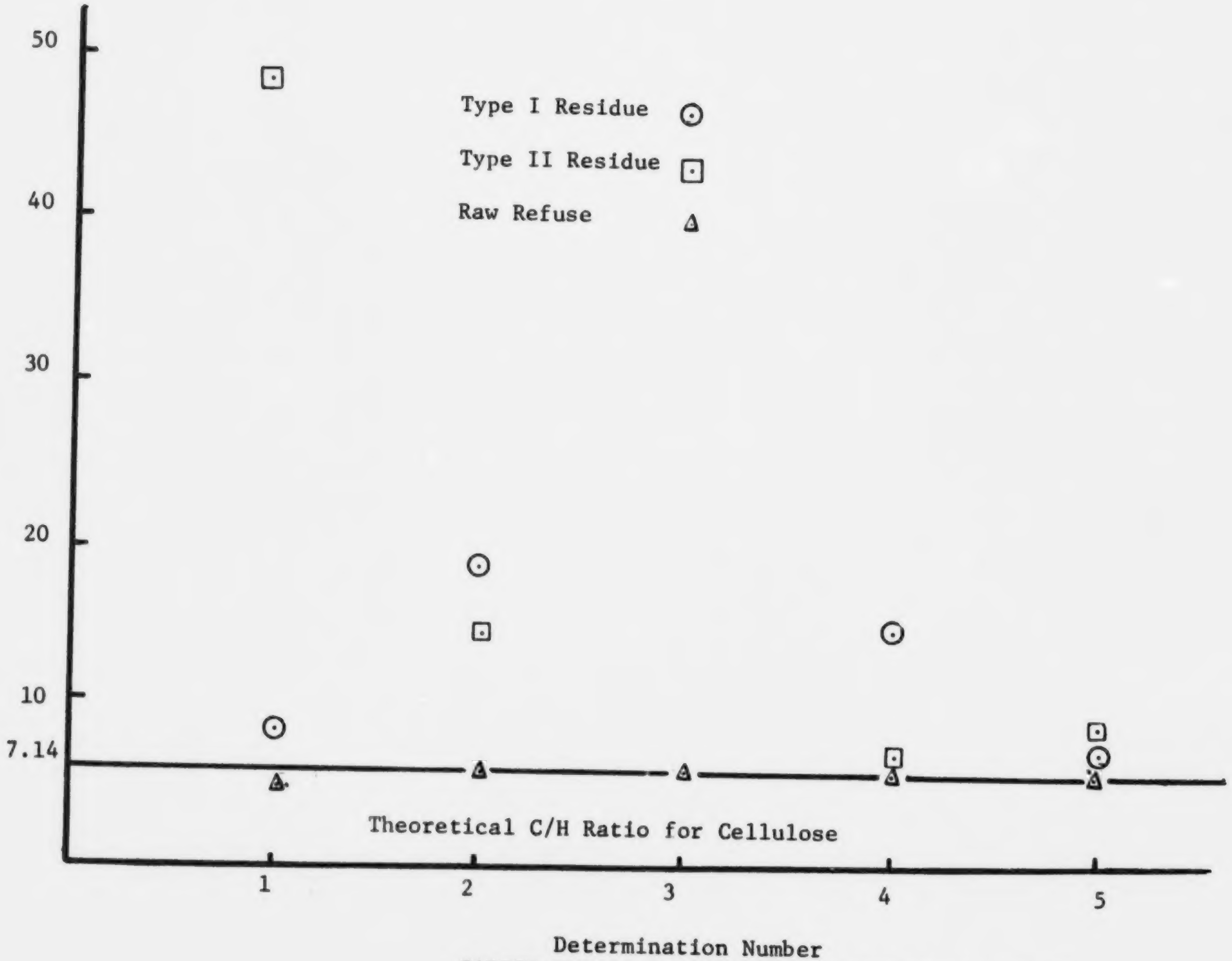
CHEMICALLY DECOMPOSABLE ORGANIC VS. PERCENT NITROGEN
FIGURE IV - 3



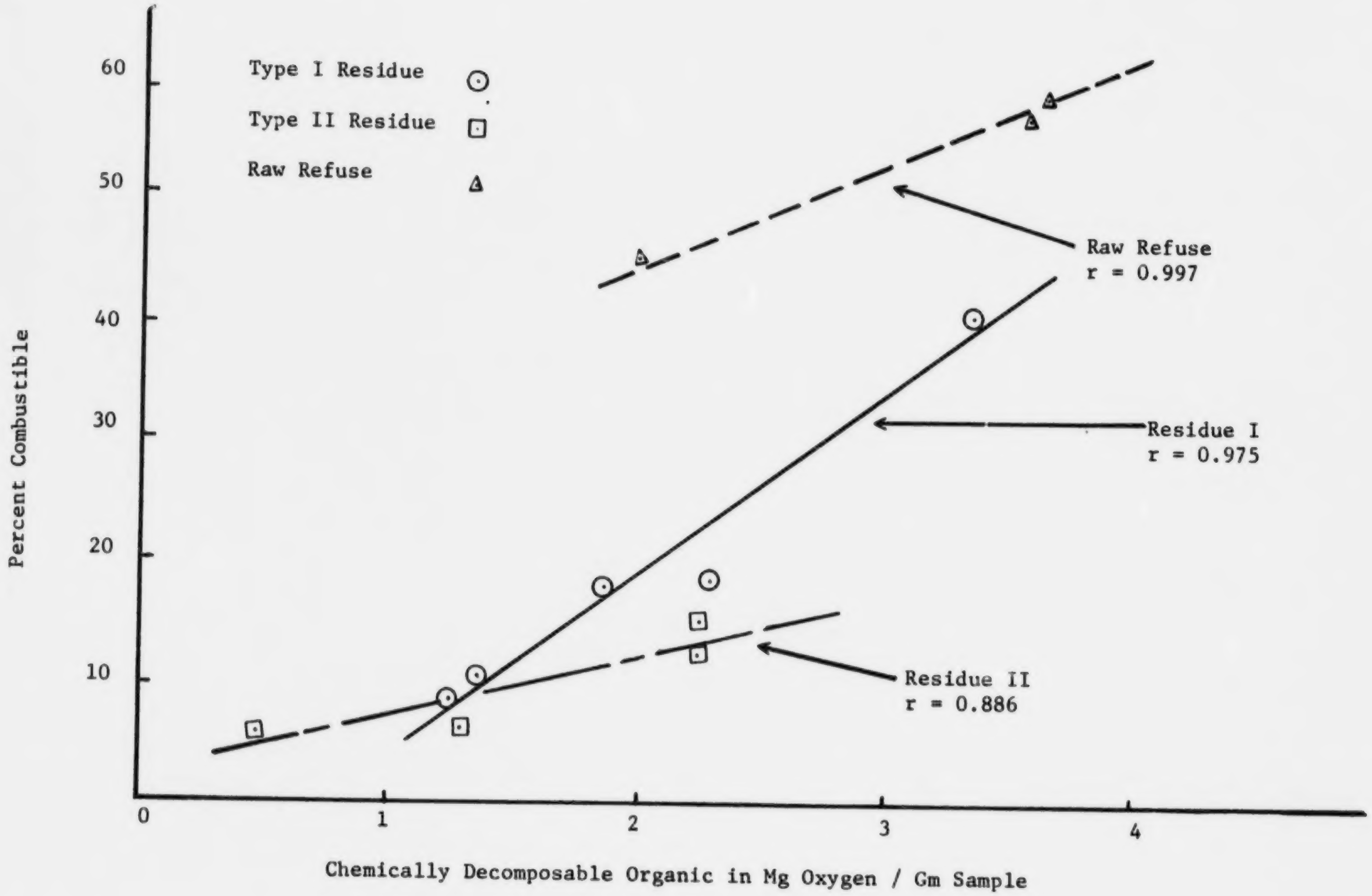
PERCENT COMBUSTIBLE VS. HEATING VALUE
FIGURE IV - 4



CHEMICALLY DECOMPOSABLE ORGANIC VS. HEATING VALUE
FIGURE IV - 5



CARBON HYDROGEN RATIO VS. DETERMINATION NUMBER
FIGURE IV - 6



CHEMICALLY DECOMPOSABLE ORGANIC VS. PERCENT COMBUSTIBLE
FIGURE IV - 7

In Figure IV - 2 the data for heating value/percent carbon are plotted. It can be seen that positive correlation was obtained only for raw refuse (r = 0.940), while both type I and type II residues indicate no correlation, (r = 0.641 and 0.46 respectively).

Interpretation of the data presented in Figure Iv - 2 begins by studying the composition of raw refuse and incinerator residue as reported in several studies (19, 29). These studies present data on the manual separation of waste into its components by the schemes given in Table II - 1. The results indicate that the percent of paper in refuse varied from 53 percent to 55 percent by dry weight of sample. When refuse has a single component (cellulose as paper) composing greater than 50 percent of its total weight, it is expected that this large influence will be reflected in the results of analyses.

It was previously stated that the heating value of cellulose was 7520 Btu per pound. The percent of carbon in cellulose is 44.5 percent, and if the percent carbon in cellulose is placed into the regression curve plotted in Figure IV-2, the heating value for cellulose is closely approximated at this percent composition. Thus, the plot of heating value vs. percent carbon reflects the percent of cellulose in refuse for a paper content greater than 25 percent of the total refuse weight. No values were obtained for a carbon percent of less than 20 percent.

As the heating value decreases in the residue, the slope of the regression equation decreases. The correlation coefficients for the curves of heating value vs. percent carbon in type I and type II residue indicate no correlation.

In Figure IV -3 are plotted CDO vs. percent nitrogen. While the correlation coefficient indicates positive correlation, the inverse relationship existing cannot be readily explained. CDO is a measure of the organic content including nitrogen bearing material; e.g., protein and amino acids. The complex protein molecules may be the portion of CDO most resistant to degradation, hence the inverse relationship.

In Figure IV - 4 are plotted the combustible fraction in percent vs. heating value in Btu per pound for the two residues and raw refuse. There is correlation for both of the residues and the raw refuse. The regression equations for the two residue fractions are indeed similar. It is easy to predict that the combustible fraction is directly proportional to heating value because raw refuse contains more components which are combustible at low temperatures. These components will be consumed at even low furnace temperatures. Percent combustible is sometimes suggested for use as an indicator of furnace performance. Correlation between the percent combustible and the heating value gives supporting evidence for using percent combustible as an indicator of furnace performance.

In Figure IV - 5 are plotted CDO vs. heating value in Btu per pound. The figure shows that for a given CDO there is a higher heating value in raw refuse than for either type of residue. A completely satisfactory explanation for the large divergence between the equations is not available. For any given CDO, one would expect to have a slightly higher heating value in raw refuse since the percent combustible is higher in raw refuse than in either type of residue. It is obvious that per pound of carbon the heating value of cellulose is higher than for fixed carbon, and CDO is a measure of organic carbon in the solid waste.

In Figure IV - 6, a plot has been made of percent carbon/percent hydrogen vs. determination number. Plotted also as a horizontal line on the figure is the theoretical C/H ratio for cellulose, approximately equal to 7.14. It is seen that the C/H ratio obtained for five samples of raw refuse coincides almost perfectly with the theoretical C/H ratio of cellulose, while in the case of residue there is a deviation from this calculated ratio. It appears that there is a greater amount of carbon in residue for a given hydrogen content. This probably results from the presence of free carbon in residue as previously discussed.

In Figure IV - 7 are plotted the chemically decomposable organic content vs. percent combustible fraction. All three curves have a positive correlation coefficient, and it is expected that this relationship would exist. The curve for raw refuse is at a higher percent of combustible fraction for a given value of CDO than are either type of residue. This indicates that refuse contains in the combustible fraction materials which are combustible yet resistent to organic decomposition. One such fraction is cellulose which is found in refuse in quantities about 25 per cent of the dry weight fraction.

RESIDUE CHARACTER BY TYPE OF FURNACE

In Table IV - 14 data are presented which extend the residue characterization to six incinerators in five geographical locations. The types of incinerators include two batchfeed units and four continuous feed units. The four continuous feed incinerators include two with traveling grates and two with rotary kiln construction similar to Figure II - 3.

The lowest percentage of combustible material was found in the residue from both rotary kiln furnaces and from one of the traveling grate units. The measured difference of the combustible fractions among the

TABLE IV - 14

RESIDUE COMPARISON BY TYPE OF FURNACE [a]

(1) Location	(2) Type of Incinerator	(3) Percent Combustible	(4) Percent Water Soluble	(5) Percent Ether Soluble
Abington Twp., Pa.	Batch, Reciprocating	13.13	3.56	1.13
Atlanta, Georgia	Continuous, Kiln	10.29	1.85	----
Delaware County, Pa.	Continuous, Traveling	19.78	1.52	0.78
Philadelphia, Pa.	Batch, Cylindrical	19.44	5.62	2.43
Louisville, Ky.	Continuous, Kiln	10.75	3.54	0.24
Philadelphia, Pa.	Continuous, Traveling	10.72	5.48	0.52

[a] All Results reported as percent by dry weight

three incinerators is less than 0.5 percent. The highest combustible fraction was also found in a traveling grate unit.

The percentage of water soluble material from the incinerators varies over a wider range than does the combustible fraction. The water soluble range is from a low in Delaware County (traveling grate) to a high value for the cylindrical batch feed incinerator. The ratio between the high (5.62 percent) and low (1.52 percent) values is 3.5. This means that for each 100,000 tons of landfilled residue between 1.52 and 5.62 tons of dissolved solids are discharged into the surface streams or underground waters.

The magnitude of the ether soluble percentage is less for each type of incinerator than for the corresponding water soluble percentage. The range of this fraction is from 0.24 percent for a rotary kiln unit to a high of 2.43 percent for a batch feed, cylindrical incinerator.

Comparison of the degree of burnout for the incinerators discussed in Table IV - 14 are presented in Table IV - 15. Burnout was calculated using Equation III - 6 where the necessary data were available. If data on the character of raw refuse were not available, Equation III - 7 was used to calculate burnout.

From Table IV - 15, it is seen that four of the six incinerators showed a burnout of greater than 90 percent. The other two burnouts were 81.75 and 75.40 percent respectively. For the four units having a burnout greater than 90 percent three were continuous feed and one was a batch feed unit. The two incinerators having a burnout of less than 90 percent were evenly divided at one batch feed and one continuous feed unit.

Based upon the data in Table IV - 15 it appears that a batch feed furnace can be operated almost as effectively as a continuous feed unit.

TABLE IV - 15

COMPARISON OF BURNOUT

(1) City	(2) Percent Combustible	(3) A_o / V_o	(4) Percent Burnout
Abington Twp., Pa.	13.13	0.63	90.45
Atlanta, Ga.	10.29	0.67	92.32
Delaware Co., Pa.	19.78	0.88	81.75
Philadelphia, Pa. (Northeast)	19.44	1.02	75.40
Louisville, Ky.	10.76	0.67	91.93
Philadelphia, Pa. (Northwest)	10.72	0.72	91.81

The table also shows that municipal incinerators do not consume all of the combustible material during existing furnace retention time.

Data presented in Tables IV - 14 and 15 were based upon the analyses of random samples. The effect of incinerator operation cannot be lightly discussed, and before each type of design can be thoroughly evaluated, the effect of operation on residue character must be studied.

In comparing the percent combustible fraction with CDO, heating value, and percent carbon it was stated that a large weight percentage of the combustible fraction was present as cellulose. The quantification of cellulose is based upon the existence of several types which are called alpha and beta cellulose. In order to avoid specific procedures for cellulose the crude fiber technique was used as an estimate of the amount of cellulose present in residue. Crude fiber has been used for a general breakdown of constitutents in food, especially animal feeds.

Table IV - 16 summarizes the relationship between the percent combustible and crude fiber fractions. Crude fiber analyses were performed by a consultant. It can be seen that for all samples of residue the percent of crude fiber in the combustible fraction was between 43.75 and 84.35. As has been previously assumed, the percent of cellulose in the combustible fraction of residue is appreciable.

RESIDUE CHARACTER - EFFECT OF TIME

One of the objectives of this dissertation was to study the environmental interactions between residue and the water or land environment into which it is placed. The analyses of residue and refuse which have been reported in this section related mostly to identification of parameters which could result in probable interaction. All parameters which were measured indicated that the character of residue which is landfilled for ultimate disposal is capable of environmental interaction.

TABLE IV - 16

RELATIONSHIP OF CRUDE FIBER TO COMBUSTIBLE FRACTION

(1) Type of Incinerator	(2) Crude Fiber (Percent by Dry Weight)	(3) Combustible Fraction (Percent by Dry Weight)	(4) Percent Crude Fiber of Percent Combustible
Continuous	6.86	9.60	71.45
Batch	21.14	44.20	47.81
Batch	15.84	18.80	84.35
Continuous	7.95	15.90	49.99
Batch	7.22	16.50	43.75

In Table IV - 17 are presented results of analyses of samples which show the residue character at the time of field placement and after one year of field exposure. The moisture content after one year (less than one percent) is much below the moisture content existing at the time of placement. The combustible fraction decreased to 3.06 percent while the iron concentration increased to 23.82 percent. The small combustible fraction was probably the result of free carbon in the residue. The increase in iron concentration is only a relative increase as a result of leaching of water soluble components and from the decomposition of part of the combustible fraction.

Decomposition of the substances in residue, which can be either aerobically or anaerobically consumed, will effect not only the quality of residue with time, but also the environmental interaction. The leachate analyses shown in Table IV - 9 were taken when the temperature of the leachate was raised from decomposition. The temperature of the leachate rose to a maximum 41 degrees C. This elevated temperature was maintained for three years, and it was not until several months after the filling operation ceased that both the leachate flow rate and temperature began to subside. Nine months after the active landfilling was ended, the leachate temperature was 33 degrees C.

Attendant to the high leachate temperature was the evolution of gaseous products of decomposition. The gas temperature maintained a level of 54 degrees C. when the leachate temperature was 41 degrees C. The evolution of gases ceases almost simultaneously with the active filling.

MISCELLANEOUS TESTS FOR PARAMETERS

Table IV - 18 presents the results of a semi-quantitative spectrographic analysis for incinerator residue and unburned refuse. The three

TABLE IV - 17

EFFECT OF TIME ON RESIDUE CHARACTER[a]

(1) Test	(2) Percent When Placed	(3) Percent After One Year
Moisture	11.85	0.74
Combustible	19.02	3.06
Water Soluble	5.43	1.30
Ether Soluble	1.98	0.10
Iron	15.95	23.82

[a] All results in percent of dry weight

TABLE IV - 18

SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSIS[a]

(1) Element	(2) Type I Residue	(3) Type II Residue	(4) Refuse
Aluminum	1.0 - 5.0	<5.0	5.0
Calcium	0.X	1.0 - 5.0	1.0 - 5.0
Chromium	0.00X	0.0X	0.0X
Copper	0.0X	0.X	0.0X
Iron	<5.0	<5.0	<5.0
Lead	0.00X	0.0X	0.0X
Magnesium	1.0	5.0	5.0
Manganese	0.00X	0.0X	0.00X
Nickel	0.00X	0.0X	0.00X
Silicon	<5.0	<5.0	<5.0
Silver	N.F.	0.000X	0.000X
Sodium	1.0 - 5.0	1.0 - 5.0	5.0
Tin	N.F.	0.0X	0.0X
Titanium	0.X	0.X	0.X
Zinc	0.X	0.X	0.0X
Cadmium	N.F.	N.F.	0.0X
Vanadium	N.F.	0.00X	0.00X
Molybdenum	N.F.	0.0X	0.0X
Potassium	N.F.	1.0 - 5.0	1.0 - 5.0

---

[a] Results are reported in dry weight percent for the range of values shown.

N.F. equals not found

elements having the highest concentrations are aluminum, iron, and silicon. Unexpectedly high, is the concentration of sodium, which is about the same magnitude as iron.

The occurrence of many of the elements listed in Table IV - 18 is expected to be random. The random nature of these elements is substantiated by the fact that not all of the elements were found in every sample. Examples of this category are the metals zinc, vandium, cadmium, silver, and potassium. The absence of potassium in type I residue is somewhat more complex than the other metals because of the high concentration found in refuse and type II residue.

While this test for selected elements will only give approximate orders of magnitude, the detection of the elements can give some foresight into the character of the trace elements in refuse and residue. Not all of the elements which are found will be water soluble, but several, including calcium, iron, sodium and potassium are of concern when water quality criteria are applied to leachate.

V. RELATIONSHIPS BETWEEN RAW REFUSE AND INCINERATOR RESIDUE CHARACTERISTICS

The day to day operation of municipal incinerators is subject to many variations, and these variations result in a different efficiency (destruction of volatile material) on almost an hourly basis. Some of the factors which affect burnout include the wetness of the refuse (caused by precipitation), temperature of the furnace, and the rate at which material is charged into the furnace. If an incinerator reaches steady-state operation (maintains a constant temperature and rate of charging), the destruction of organic matter will be fairly uniform. Steady state is rarely achieved because of the need to vary operation due to the previously mentioned refuse moisture content, the amount of refuse collected, number of inoperative furnaces, etc.

In order to see whether there is a relationship between the characteristics of refuse and the destruction of organic matter, this study was undertaken. Data were obtained from the analysis of refuse and incinerator residue samples from the City of Philadelphia's Northwest incinerator. Detailed laboratory studies were performed at Drexel University's Environmental Engineering Laboratories. The particular analyses of concern include percent moisture, percent volatile, refuse calorific value, and other pertinent information. In addition, weather data, including the daily temperature and rainfall, and the rainfall on the two days prior to taking the sample, were also taken. After all available data were gathered, a regression analysis was performed on a digital computer. The first regression program took five variables, that is, percent moisture, percent volatile, calorific value, total inches of rainfall, and temperature, and a linear regression analysis was performed on sets of two variables. The moisture content was paired with percent volatile, calorific value, etc. For each pair a scatter diagram was drawn depecting the relationships of the respective pairs. These diagrams are given as Figure V-1 through V-18. On the same diagrams the calculated regression line was also drawn and under each graph the correlation coefficient is printed along with the formula of linear regression line. In some instances a particular pair of variables were not expected to correlate, but the calculations were performed to avoid biasing the data by rejecting a pair without proof. Negative results, where they are expected, are also useful in delineating the relationship between refuse and residue.

In order to limit the effect of season, the samples were grouped according to month. In the first run, all samples taken in April, May, June, July and August were processed simultaneously. These months represent the late spring and summer months when the temperature is at a maximum. In subsequent runs the data were grouped into spring and summer months to find what effect season has on the characteristics of waste disposal. Figure V-19 lists the correlation coefficients for various groupings of the data by months. The numbers heading the columns are the months of the year which are included in that particular subset. A total of five columns are in Figure V-19 and they include the months of April, May, June, July and August in varying combinations. The columns present the correlation coefficients which were determined for refuse and residue for the particular months.

After partitioning the data into groups representing the spring and summer months, it became apparent that the correlation coefficients tend to increase in strength as the five spring and summer months are separted into smaller groups. One possible explanation for this occurrence is that the correlation between two variables is weakened by the introduction of extraneous factors caused when the data are collected over too long a time. In other words, more uniformity of unmeasured variables can be expected for periods of two or three months when compared to a five month period.

On the whole, the results as shown in Figure V-19 are impressive. A few outstanding correlations are found and can be considered logical conclusions, e.g., line 4, the correlations of rainfall vs. calorific value for residue seems to indicate that for the summer months, the more it rains, the higher the percent of combustibles remaining in the residue due to reduced burnout caused by wet refuse. While the correlation coefficients of line 5 could have been stronger, the results are logical. Line 5 pits the volatile fraction vs. the calorific value for refuse. Likewise, in line 13, the correlation of rainfall vs. refuse moisture content shows the expected positive correlation between rainfall and moisture. The fact that only 100 samples points for both raw refuse and residue were available is one possible reason for lack of strength in the correlation coefficients.

Strong statistical correlation could have great practical value. For instance, the test for moisture content is much more simple than the test for calorific value because the test for moisture content requires only the use of a balance and a drying oven, while calorific value requires grinders, screens, drying oven, and a highly sophisticated calorimeter with the need for ancillary chemicals and gases. It is a well accepted fact that the calorific content of refuse is an important consideration in both the design and operation of incinerators, hence is of value despite the analytical difficulties. Thus, the more complex calorific value tests could be eliminated by the moisture tests if the correlation between the two were sufficiently strong. The regression analysis would yield the linear equation which could be used to estimate the calorific value based on the moisture content. This type of reasoning could even be taken one step further, i.e., to correlate rainfall and moisture. In so doing the rainfall figures could be used to estimate the calorific value of refuse, thereby totally eliminating the need for a laboratory.

The regression lines for the 18 rows and five columns are given in Figures V-20 through V-23. These equations, together with the correlation coefficients, help to shed some light on the relationships between refuse and residue characteristics.

The relationship between refuse and residue as presented in Figures V-19 through V-23 are for linear correlation. Higher order nonlinear equations would possibly give a better fit to the data. Data were subsequently analyzed to see whether an equation of the form $y = C_o X^o + C_1 x + C_2 x^2 + --- C_n x^n$ would fit the data. The coefficients obtained from this testing were not as significant as was the test for linearity. In fact, none of the correlation coefficients were improved with the higher order nonlinear equations.

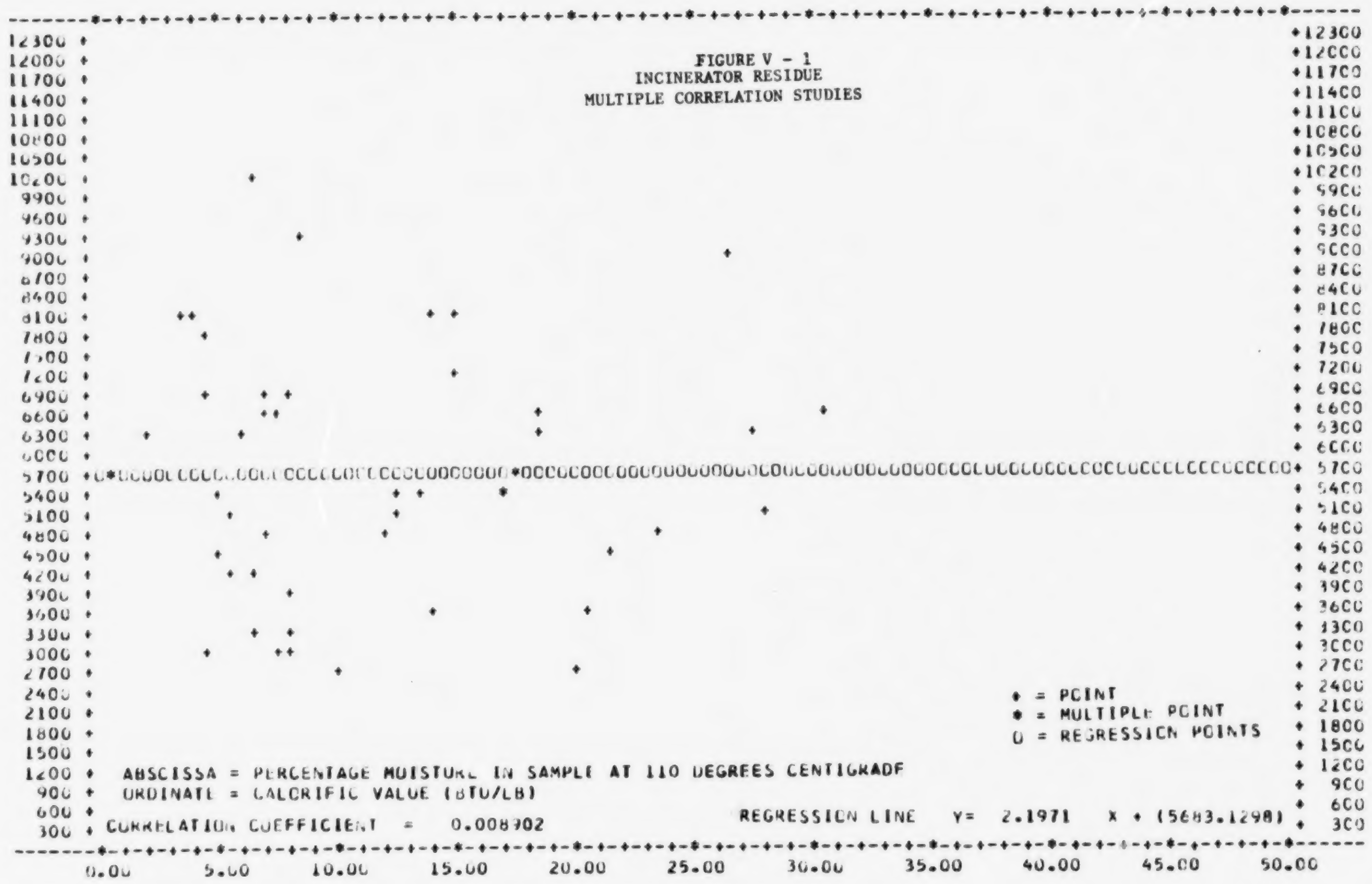
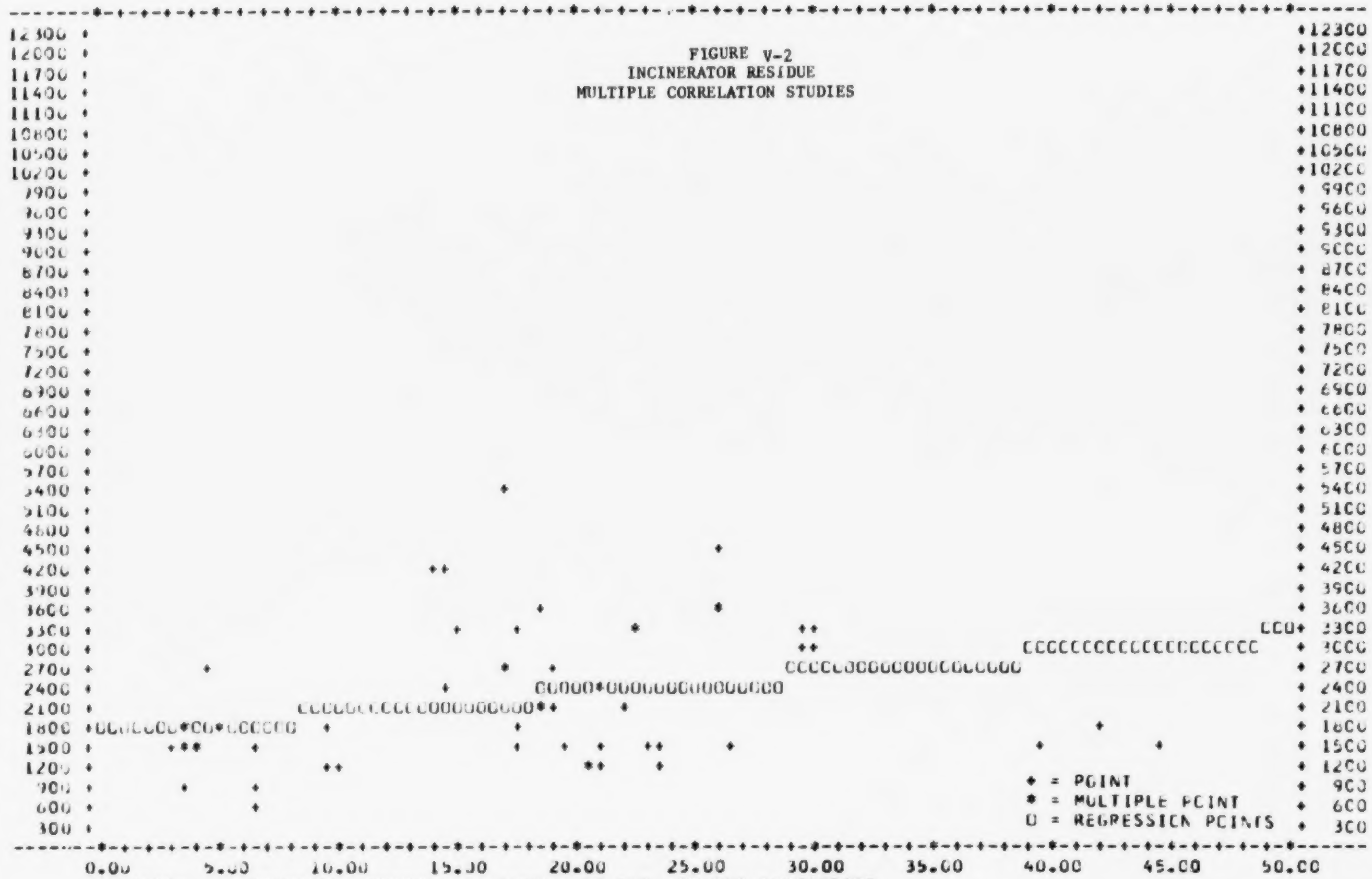


FIGURE V - 1
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

ABSCISSA = PERCENTAGE MOISTURE IN SAMPLE AT 110 DEGREES CENTIGRADE
ORDINATE = CALORIFIC VALUE (BTU/LB)
CORRELATION COEFFICIENT = 0.008902
REGRESSION LINE Y= 2.1971 X + (5683.1298)

FIGURE V-2
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES



ABSCISSA = PERCENTAGE MOISTURE IN SAMPLE AT 110 DEGREES CENTIGRADE
ORDINATE = CALORIFIC VALUE (BTU/LB)

REGRESSION LINE Y= 29.6779 X + (1701.3584)

CORRELATION COEFFICIENT = 0.257705

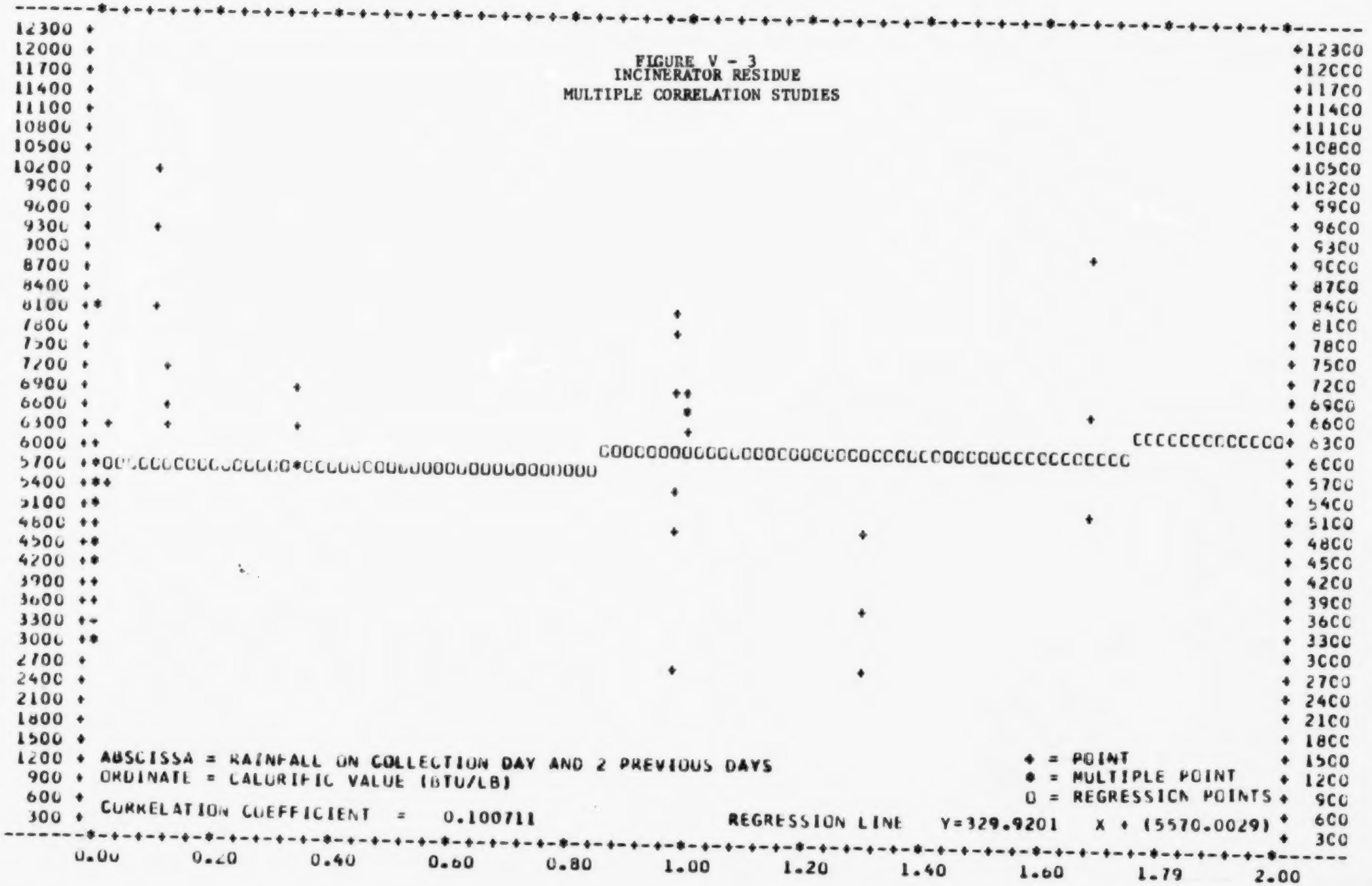


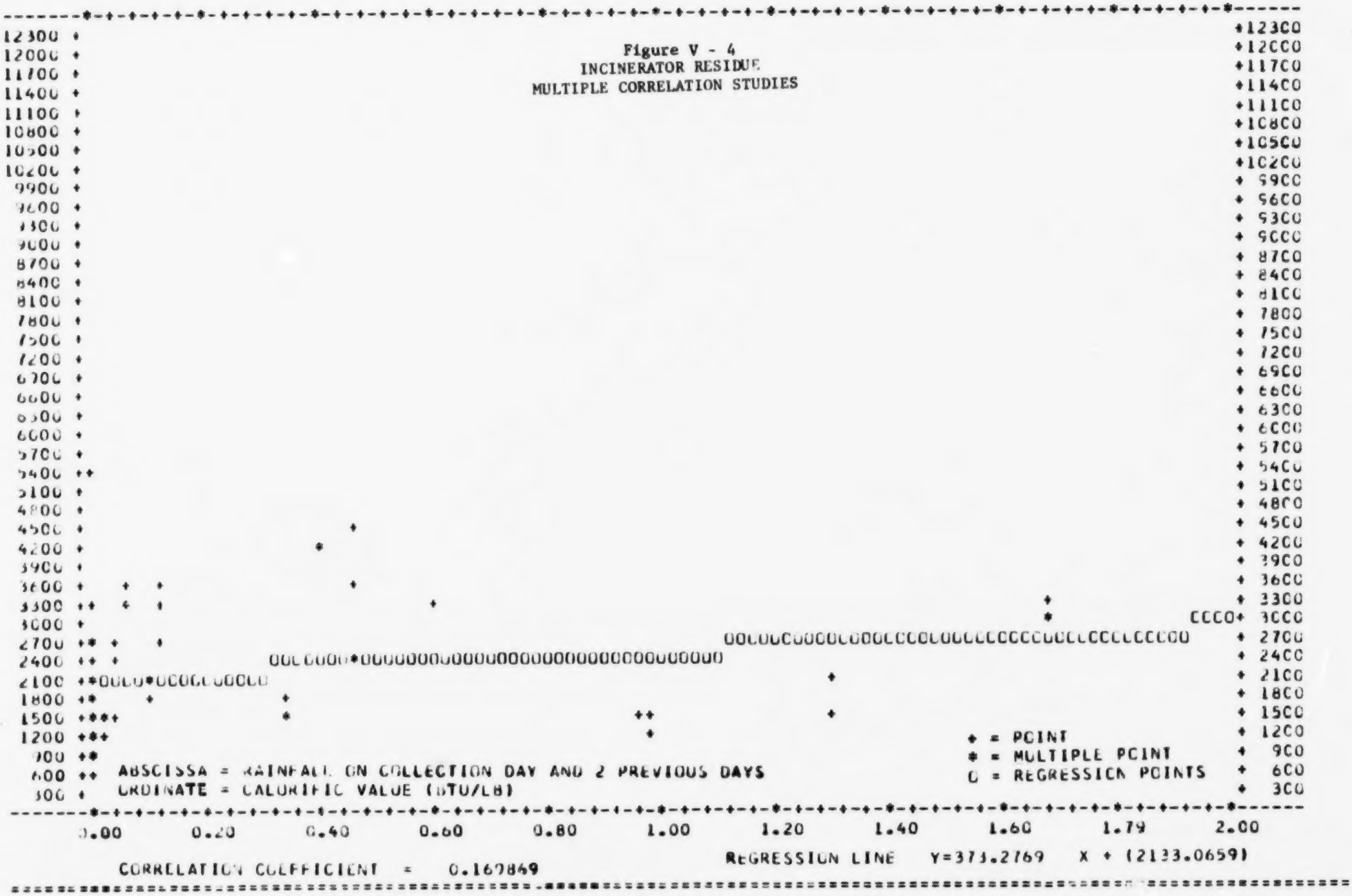
FIGURE V - 3
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

ABSCISSA = RAINFALL ON COLLECTION DAY AND 2 PREVIOUS DAYS
ORDINATE = CALORIFIC VALUE (BTU/LB)
CORRELATION COEFFICIENT = 0.100711

REGRESSION LINE Y=329.9201 X + (5570.0029)

+ = POINT
* = MULTIPLE POINT
O = REGRESSION POINTS

Figure V - 4
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

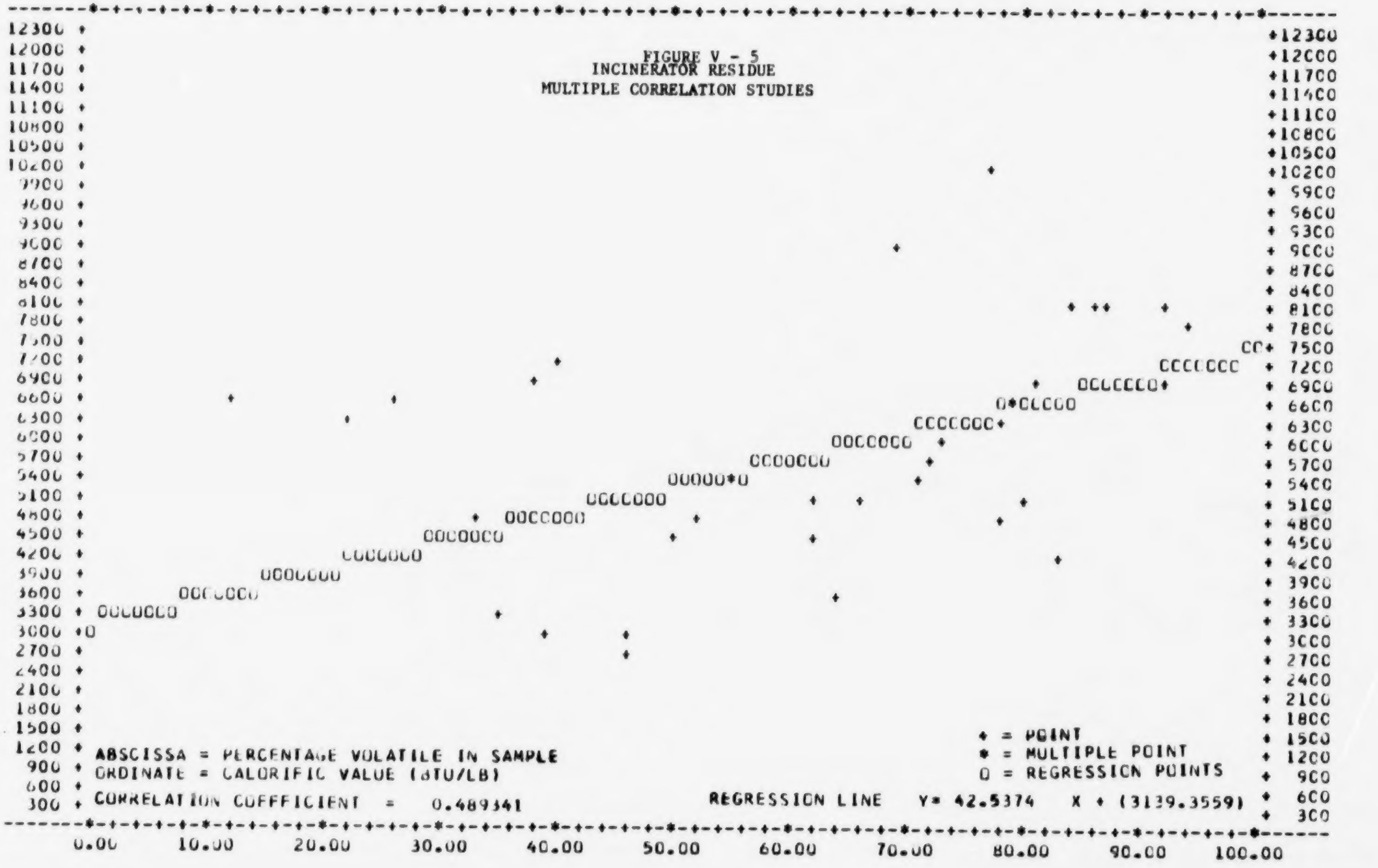


ABSCISSA = RAINFALL ON COLLECTION DAY AND 2 PREVIOUS DAYS
ORDINATE = CALORIFIC VALUE (BTU/LB)

CORRELATION COEFFICIENT = 0.169849

REGRESSION LINE Y=373.2769 X + (2133.0659)

FIGURE V - 5
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES



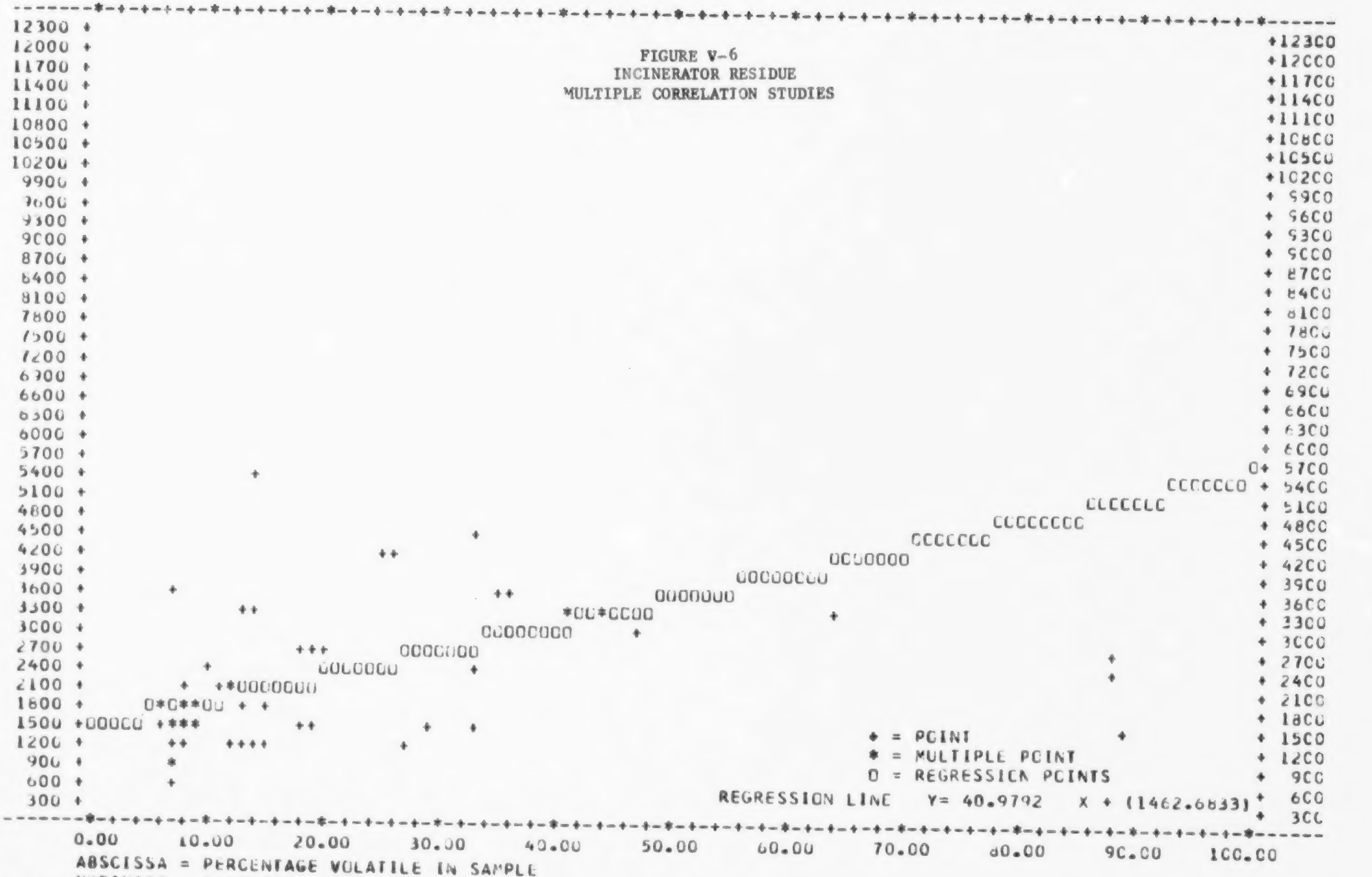


FIGURE V-6
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

+ = POINT
* = MULTIPLE POINT
O = REGRESSION POINTS

REGRESSION LINE Y= 40.9792 X + (1462.6833)

ABSCISSA = PERCENTAGE VOLATILE IN SAMPLE
ORDINATE = CALORIFIC VALUE (BTU/LB)

CORRELATION COEFFICIENT = 0.516849

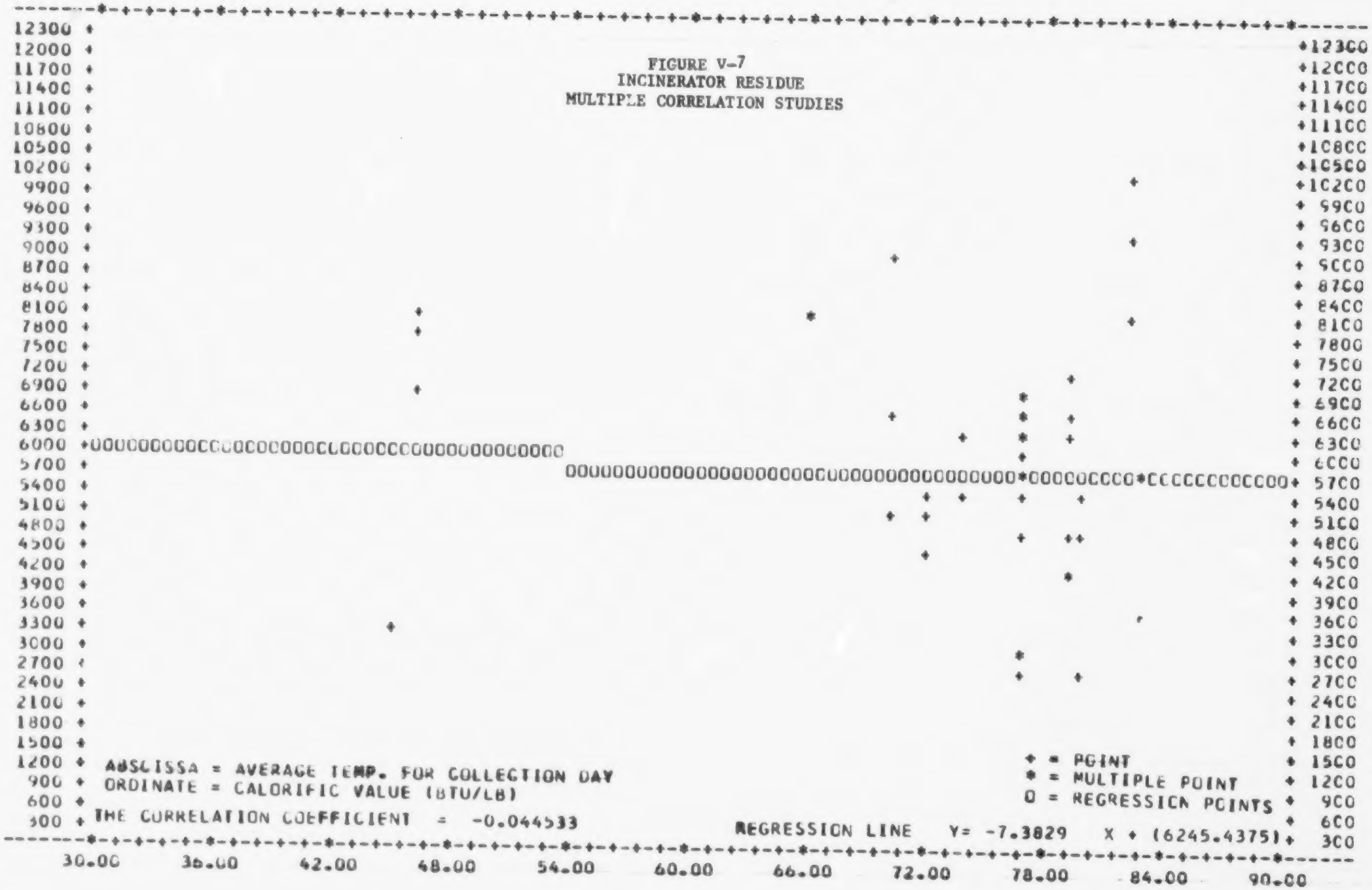


FIGURE V-7
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

ABSCISSA = AVERAGE TEMP. FOR COLLECTION DAY
ORDINATE = CALORIFIC VALUE (BTU/LB)
THE CORRELATION COEFFICIENT = -0.044533
REGRESSION LINE Y= -7.3829 X + (6245.4375)

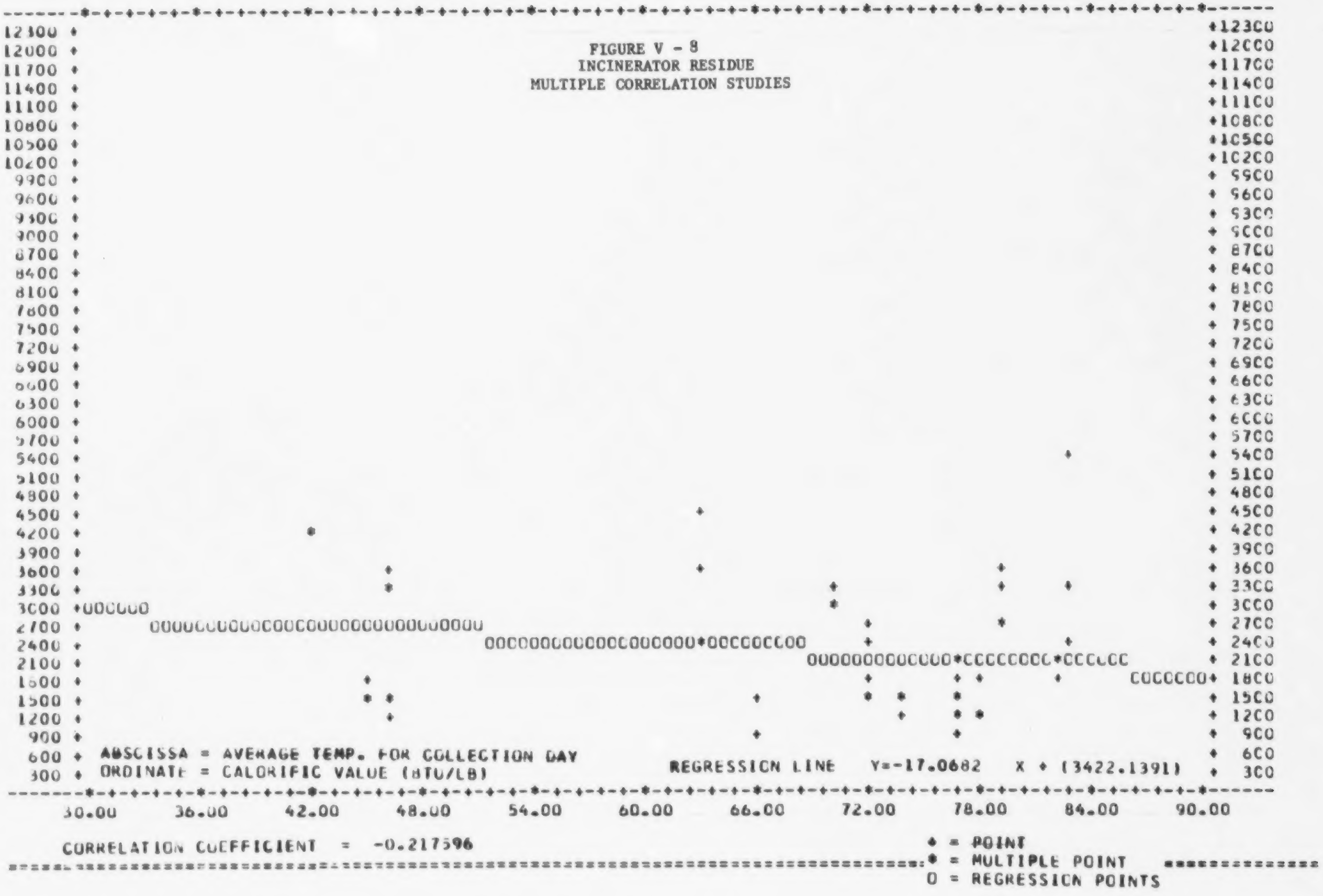


FIGURE V - 8
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

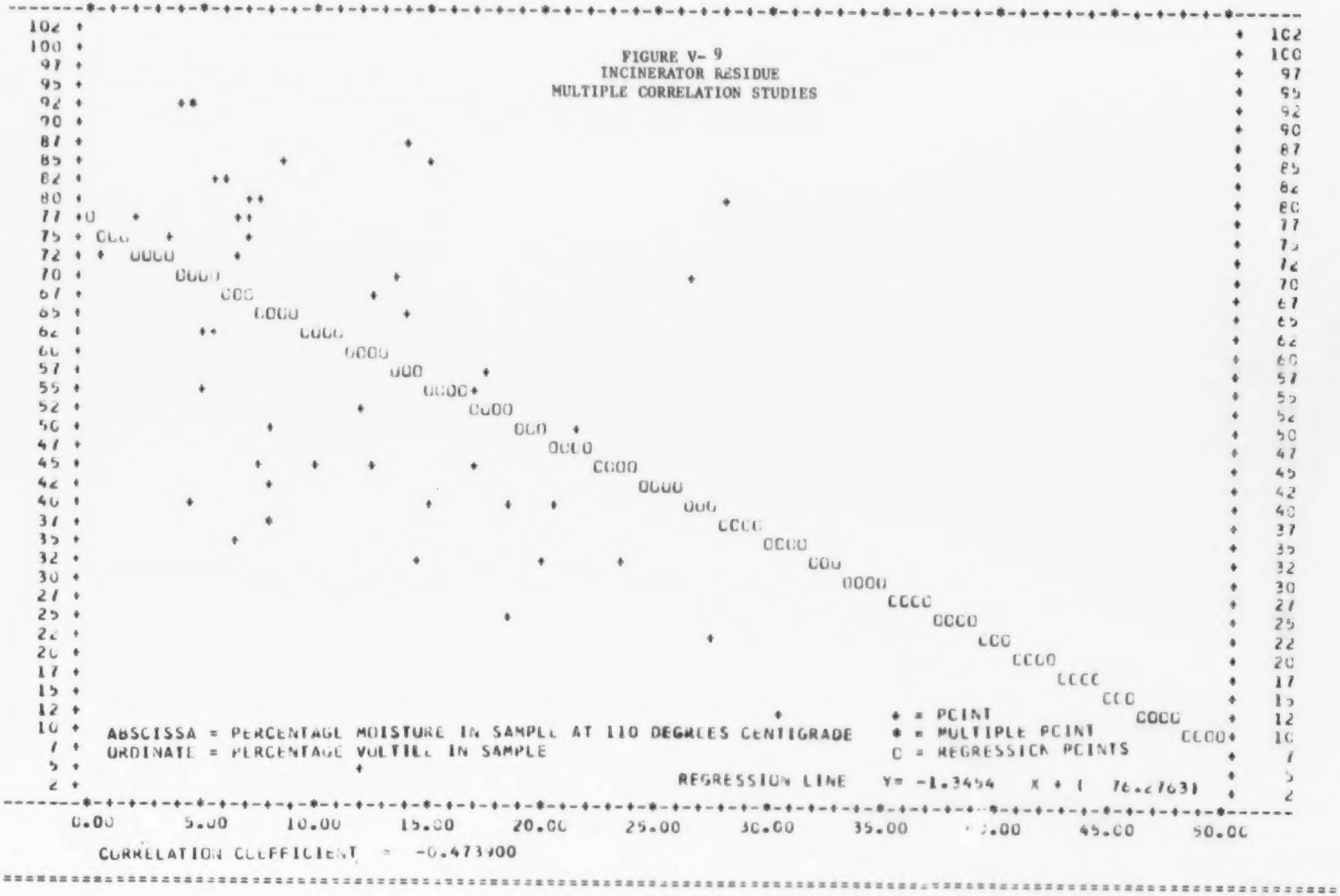
ABSCISSA = AVERAGE TEMP. FOR COLLECTION DAY
ORDINATE = CALORIFIC VALUE (BTU/LB)

REGRESSION LINE Y=-17.0682 X + (3422.1391)

CORRELATION COEFFICIENT = -0.217596

+ = POINT
* = MULTIPLE POINT
0 = REGRESSION POINTS

FIGURE V- 9
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES



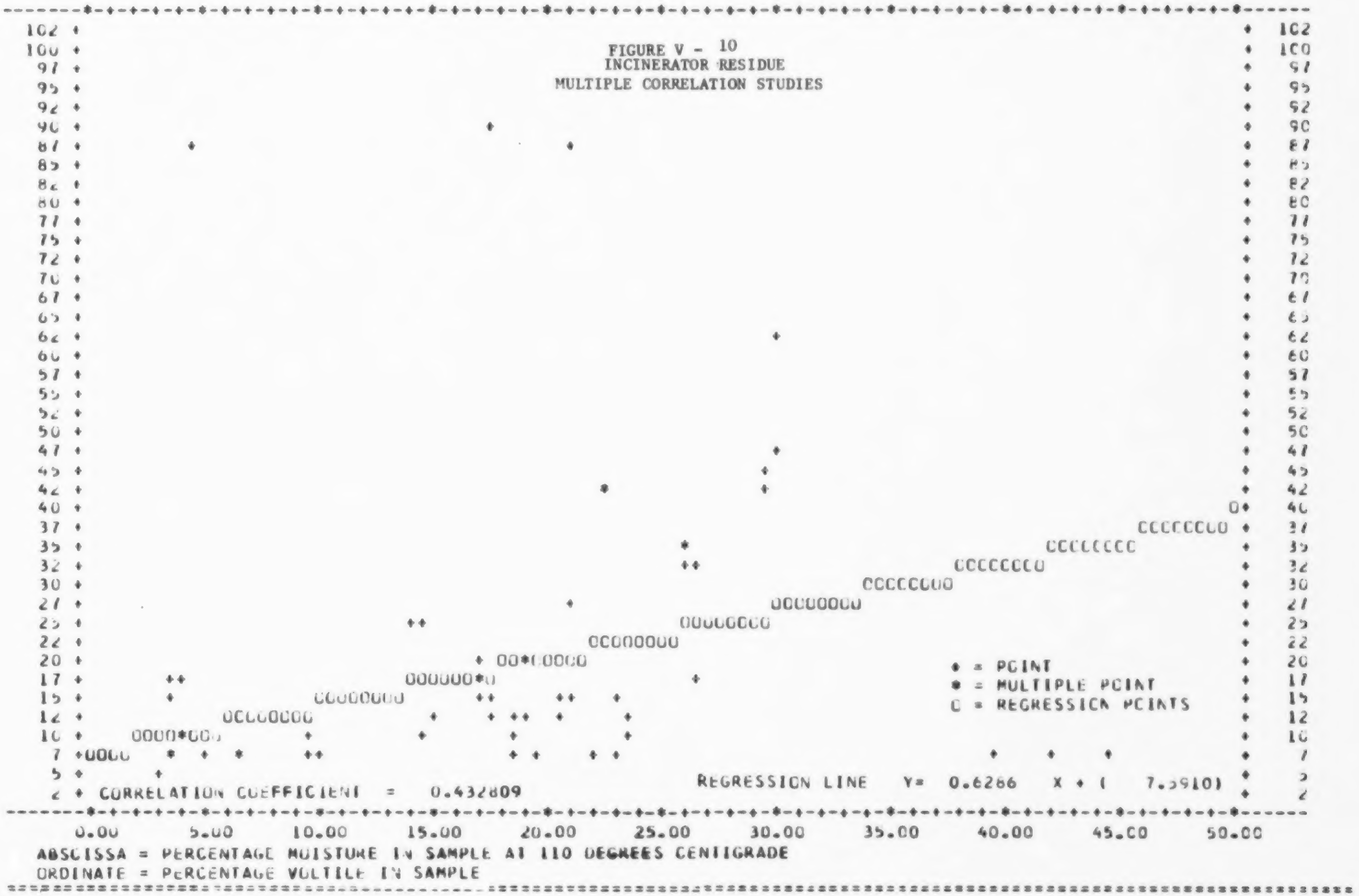


FIGURE V - 10
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

+ = POINT
* = MULTIPLE POINT
O = REGRESSION POINTS

CORRELATION COEFFICIENT = 0.432809

REGRESSION LINE Y= 0.6266 X + (7.5910)

ABSCISSA = PERCENTAGE MOISTURE IN SAMPLE AT 110 DEGREES CENTIGRADE
ORDINATE = PERCENTAGE VOLTILE IN SAMPLE

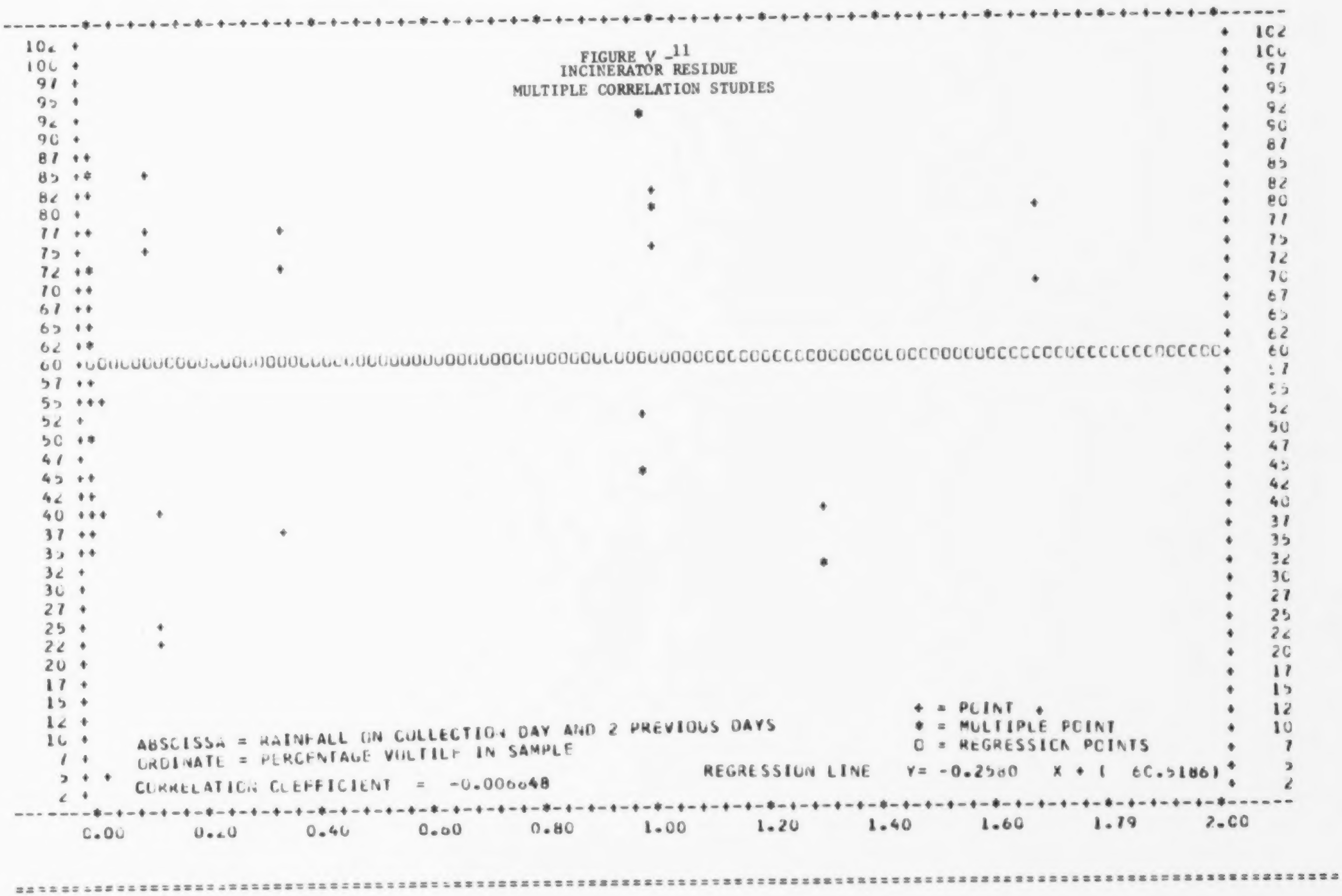
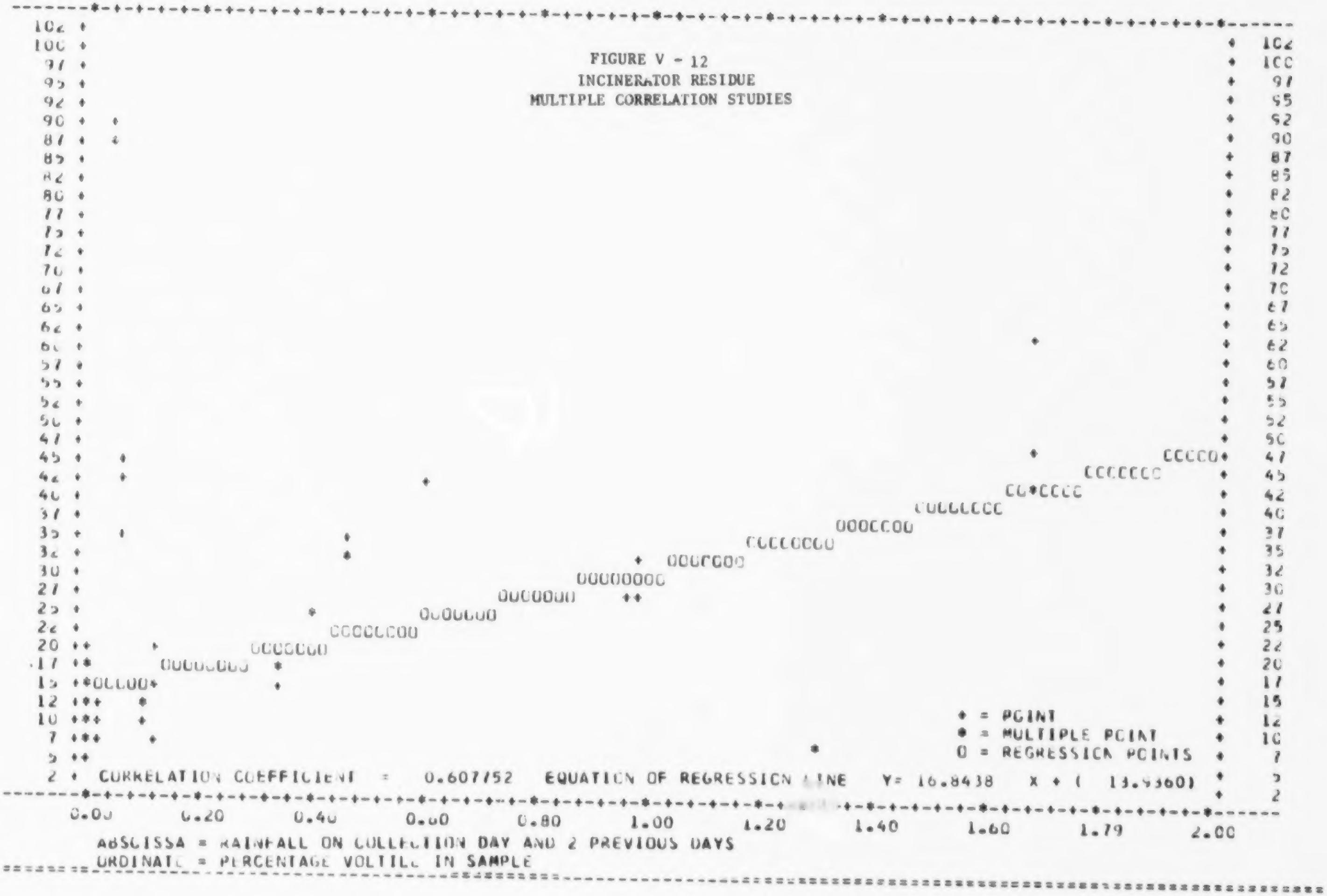


FIGURE V_11
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

ABSCISSA = RAINFALL ON COLLECTION DAY AND 2 PREVIOUS DAYS
ORDINATE = PERCENTAGE VOLTILE IN SAMPLE
CORRELATION COEFFICIENT = -0.006648

REGRESSION LINE Y= -0.2580 X + (60.5186)

FIGURE V - 12
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES



CORRELATION COEFFICIENT = 0.607752 EQUATION OF REGRESSION LINE Y= 16.8438 X + (13.9360)

ABSCISSA = RAINFALL ON COLLECTION DAY AND 2 PREVIOUS DAYS
ORDINATE = PERCENTAGE VOLTILE IN SAMPLE

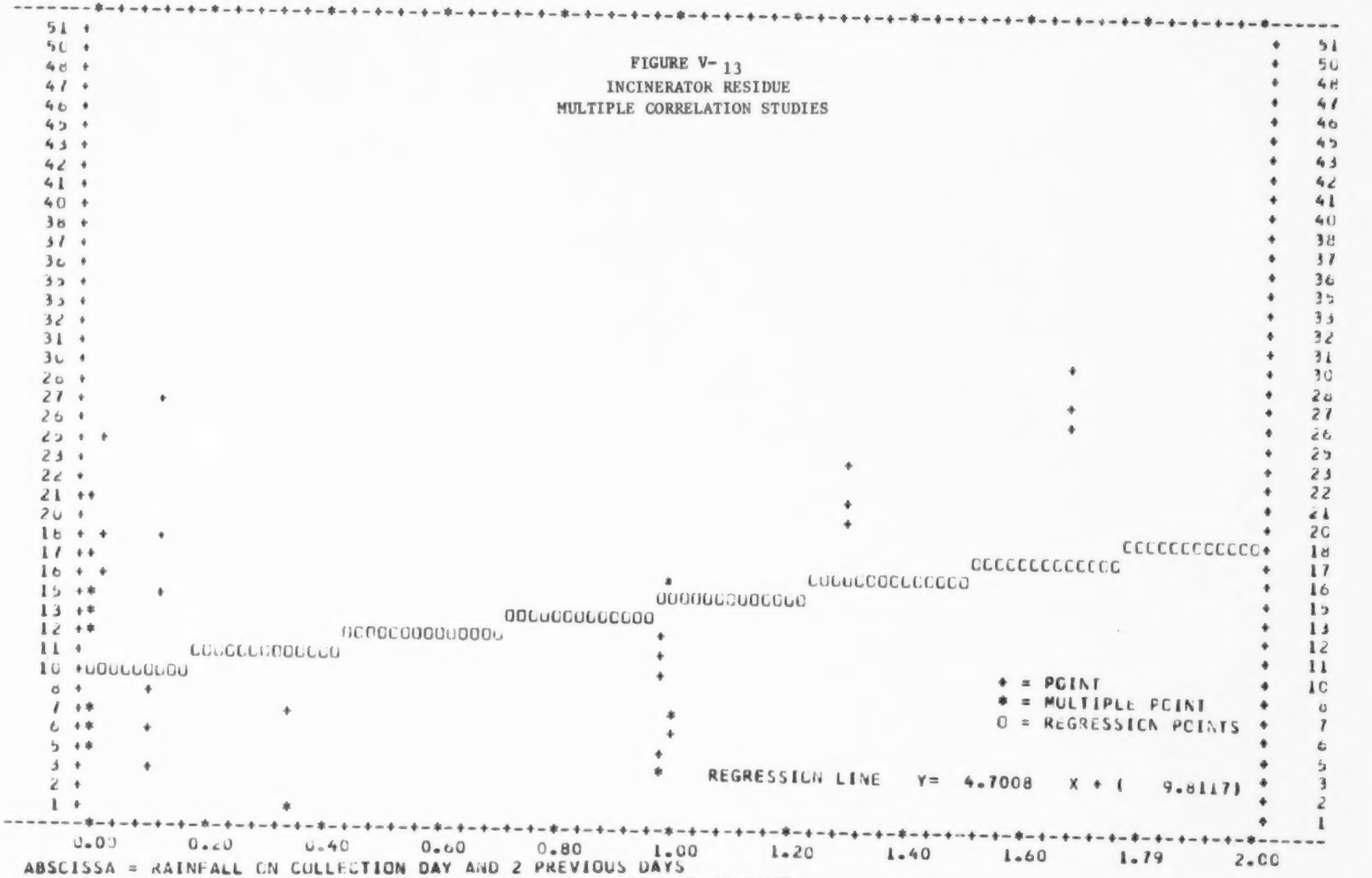


FIGURE V- 13
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

REGRESSION LINE Y= 4.7008 X + (9.8117)

ABSCISSA = RAINFALL ON COLLECTION DAY AND 2 PREVIOUS DAYS
ORDINATE = PERCENTAGE MOISTURE IN SAMPLE AT 110 DEGREES CENTIGRADE

CORRELATION COEFFICIENT = 0.354142

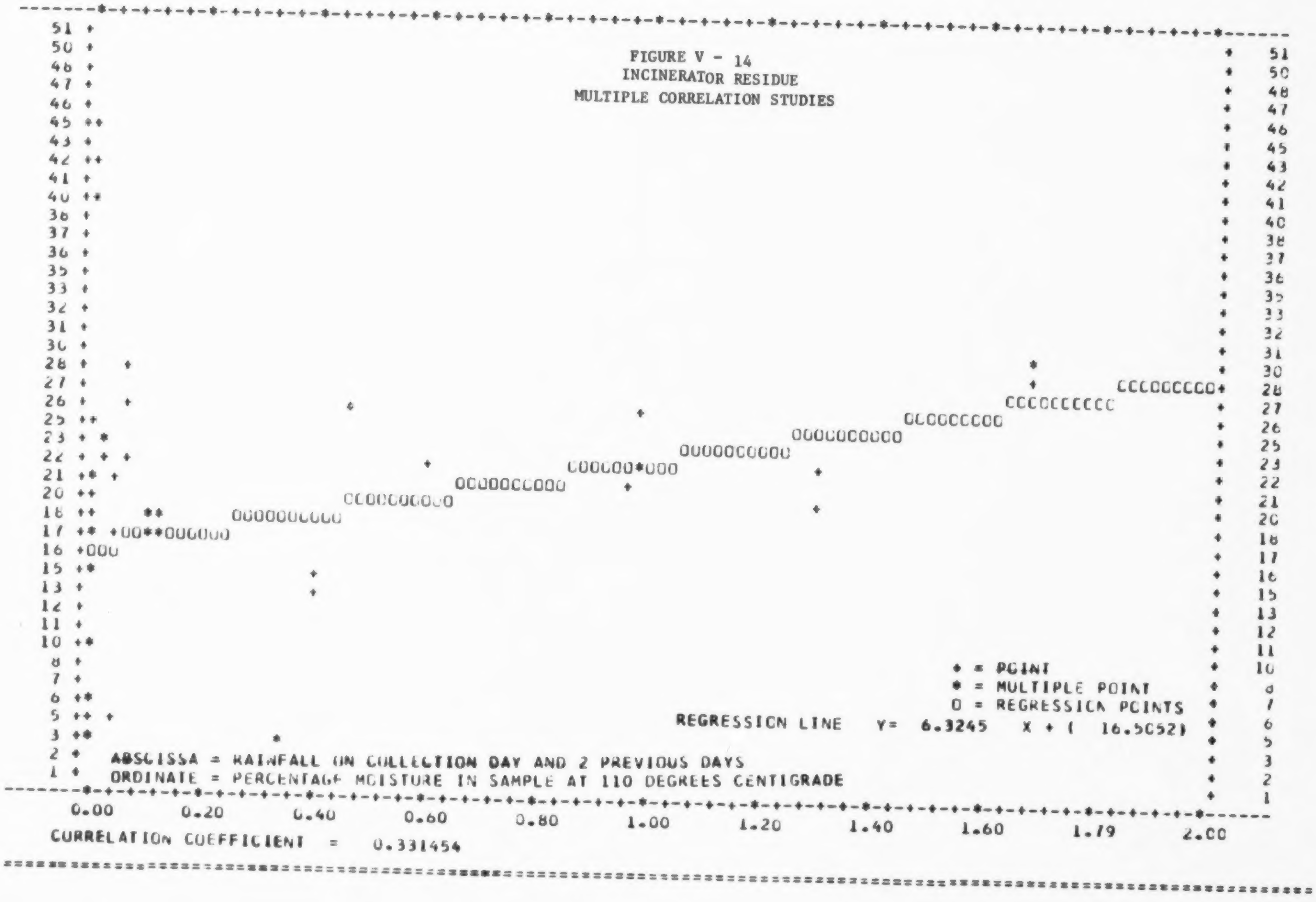


FIGURE V - 14
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

+ = POINT
* = MULTIPLE POINT
O = REGRESSION POINTS

REGRESSION LINE Y= 6.3245 X + (16.5052)

ABSCISSA = RAINFALL ON COLLECTION DAY AND 2 PREVIOUS DAYS
ORDINATE = PERCENTAGE MOISTURE IN SAMPLE AT 110 DEGREES CENTIGRADE

CORRELATION COEFFICIENT = 0.331454

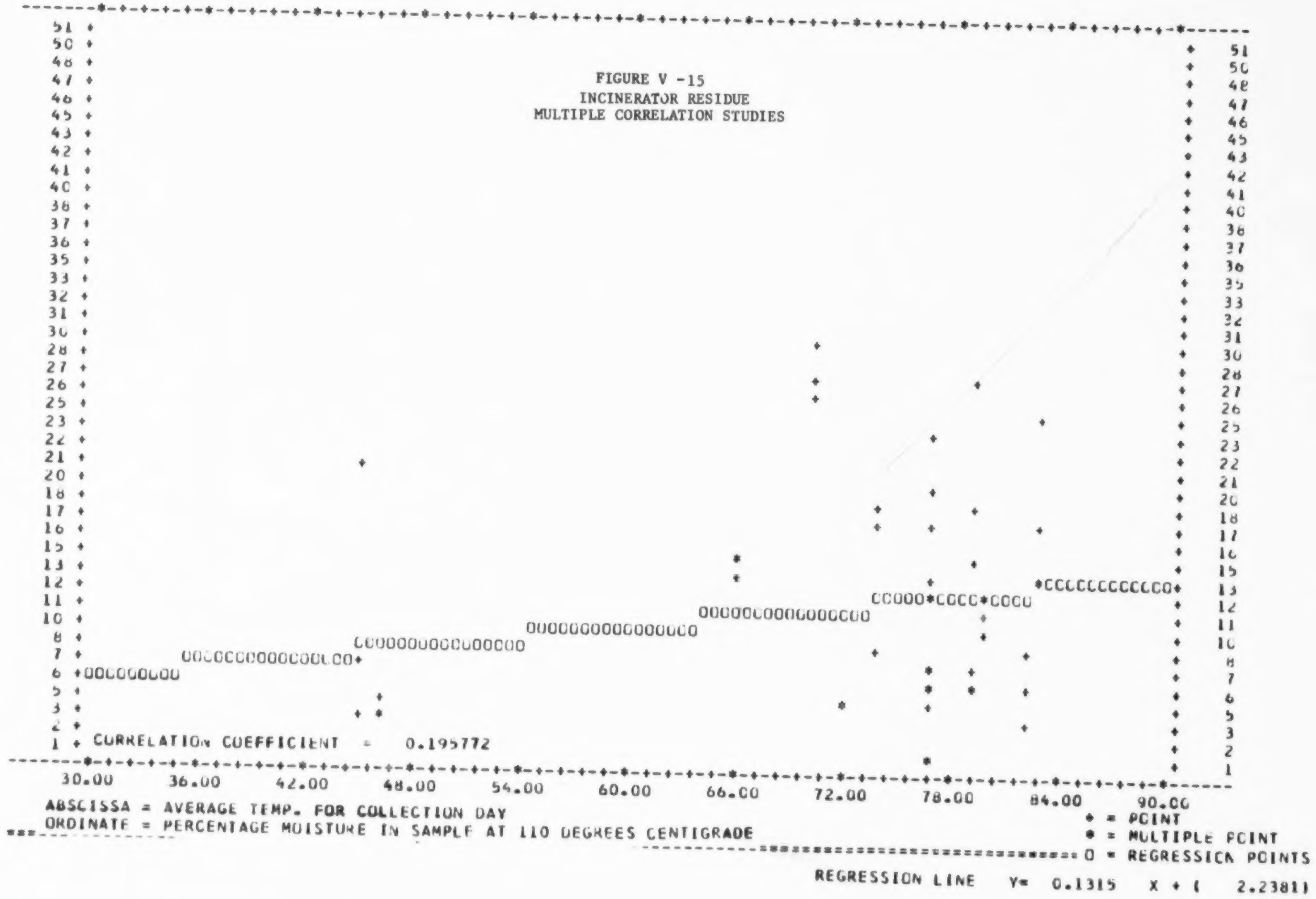


FIGURE V -15
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

CORRELATION COEFFICIENT = 0.195772

ABSCISSA = AVERAGE TEMP. FOR COLLECTION DAY
ORDINATE = PERCENTAGE MOISTURE IN SAMPLE AT 110 DEGREES CENTIGRADE

+ = POINT
* = MULTIPLE POINT
0 = REGRESSION POINTS

REGRESSION LINE Y= 0.1315 X + (2.2381)

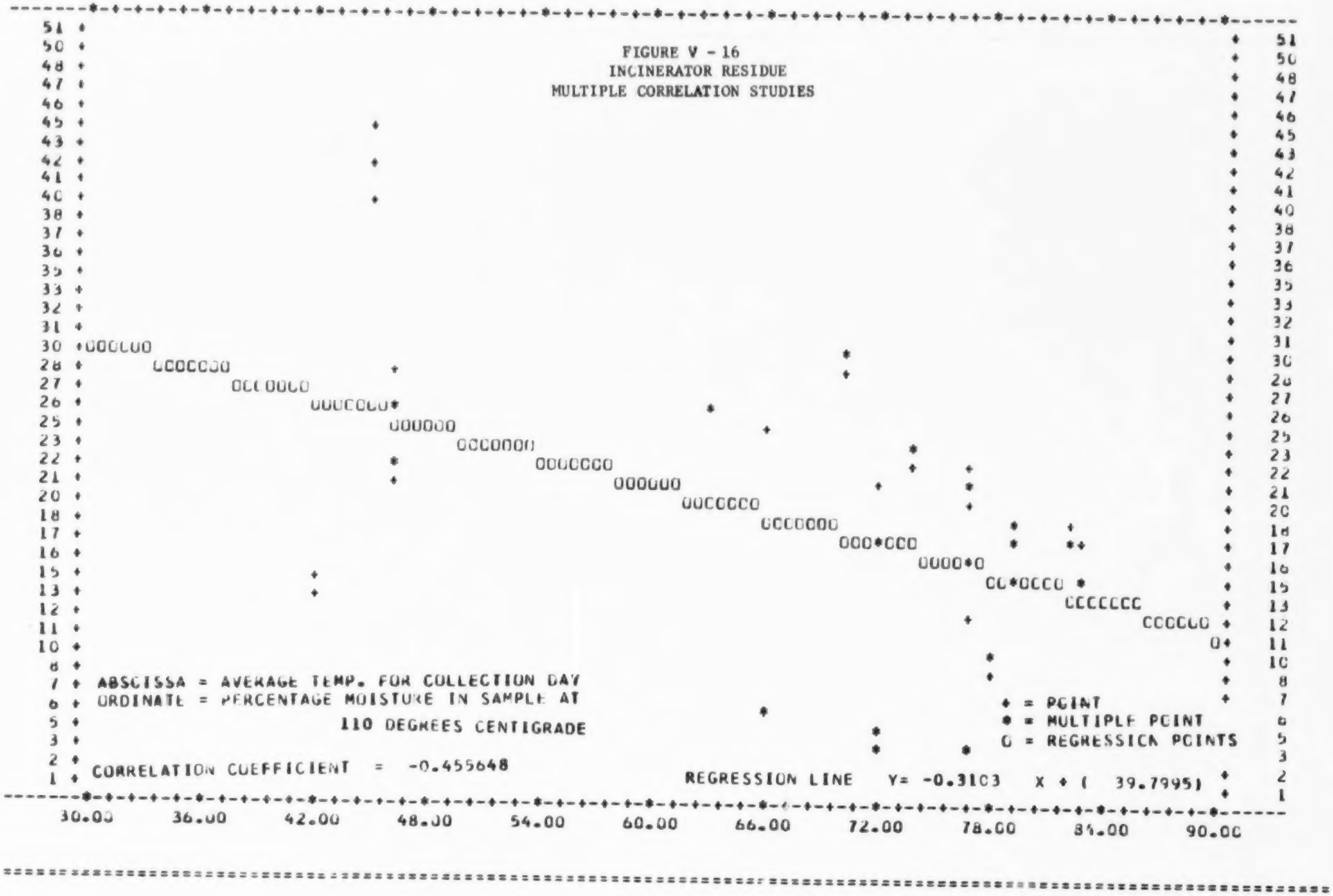


FIGURE V - 16
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

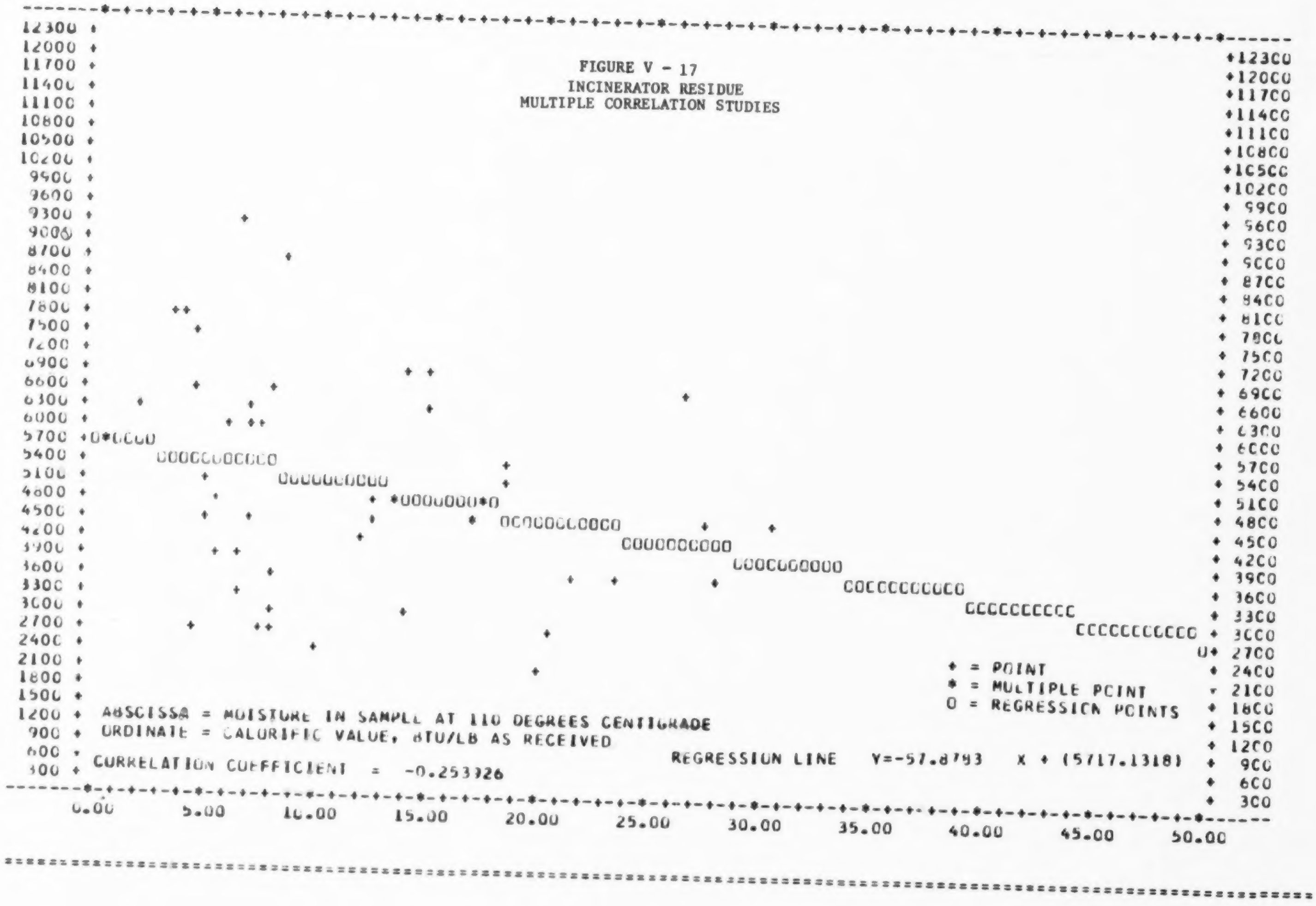


FIGURE V - 17
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

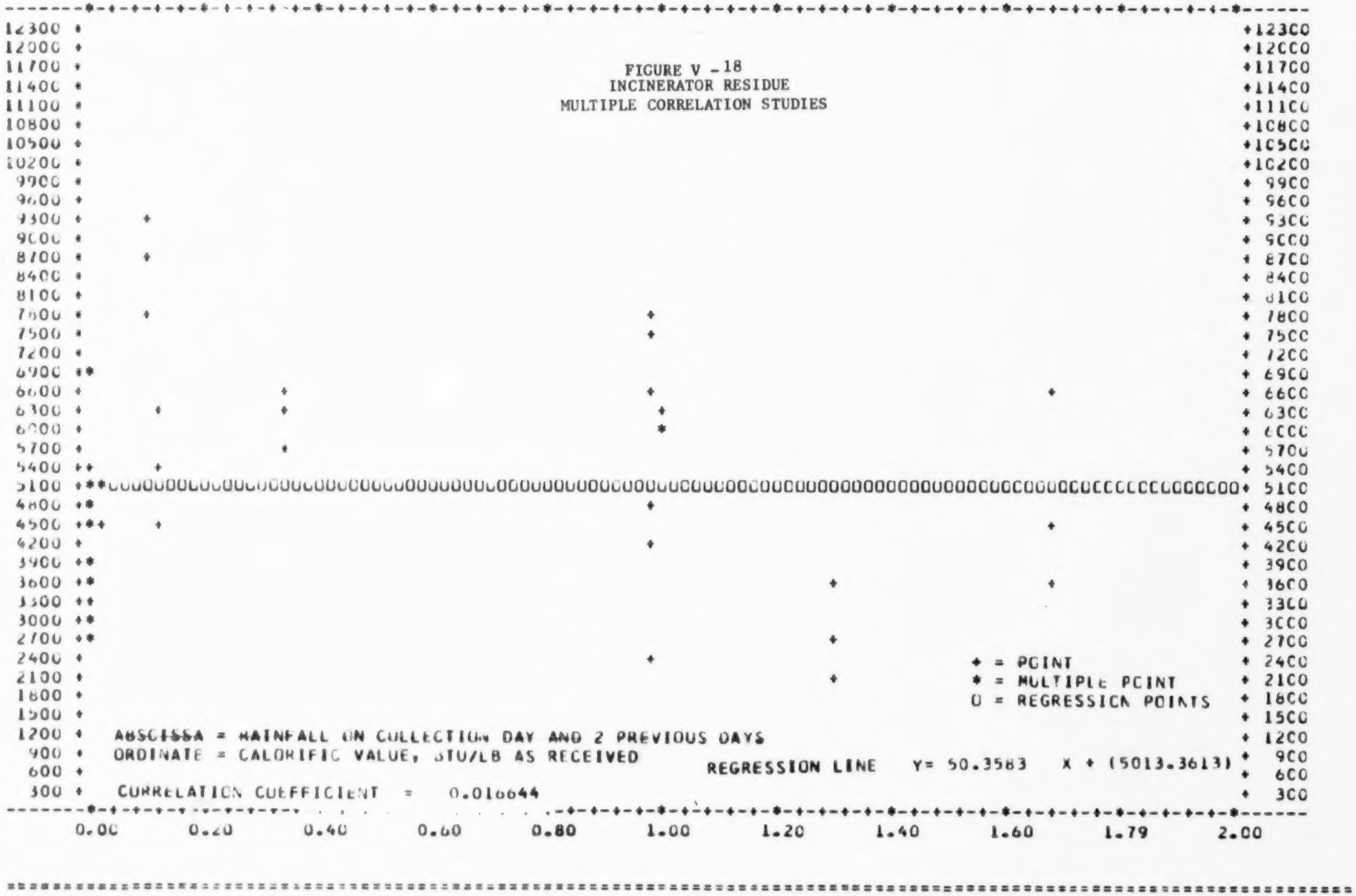


FIGURE V -18
INCINERATOR RESIDUE
MULTIPLE CORRELATION STUDIES

FIGURE 19

CORRELATION COEFFICIENTS FOR DATA

GROUPED BY MONTH

VARIABLES COMPARED		4,5,6, 7,8	4,5	6,7,8	4,5,6	7,8
1. Moisture - Calcrific value	(refuse)	0.00	0.18	-0.08	0.20	-0.28
2. " " "	(Residue)	0.26	-0.42	0.08	0.37	-0.06
3. Rainfall - Calorific value	(refuse)	0.10	0.72	-0.17	0.41	-0.15
4. " " "	(Residue)	0.17	-0.79	0.75	0.17	0.85
5. Volatile - Calorific value	(refuse)	0.49	0.52	0.48	0.40	0.59
6 " " "	(Residue)	0.52	0.13	0.35	0.50	0.42
7. Temperature-Calorific value	(refuse)	-0.04	0.33	-0.16	-0.02	0.35
8. " " "	(Residue)	-0.22	-o.64	0.40	-0.28	0.32
9. Moisture - Volatile	(refuse	-0.47	-0.37	-0.55	-0.40	-0.66
10. " "	(Residue)	0.43	0.70	-0.01	0.80	-0.19
11. Rain "	(refuse)	-0.01	0.23	-0.16	0.12	-0.17
12. " "	(Residue)	0.61	-0.51	0.36	0.70	0.89
13. Rainfall - moisture	(refuse)	0.35	0.74	0.12	0.41	0.40
14. " "	(Residue)	0.33	-0.09	-0.26	0.58	-0.33
15. Temperature - Moisture	(refuse)	0.20	0.98	-0.00	0.54	-0.39
16. " "	(Residue)	-0.46	0.86	0.34	-0.08	-0.10
17. Moisture - Calorific value, as received	(refuse)	-0.25	-0.21	-0.29	-0.16	-0.42
18. Rainfall - "	(refuse)	0.02	0.45	-0.17	0.27	-0.18

FIGURE 20

REGRESSION EQUATIONS FOR

APRIL AND MAY

EQUATION

1. $y = 34.79\ x + 5567.6$
2. $y = 94.88\ x + 5004.7$
3. $y = 2118\ x + 4145.9$
4.
5. $y = 37.9\ x + 3637$
6. $y = 20.08\ x + 2238.5$
7. $y = 58.2\ x + 2909.9$
8.
9. $y = 0.946\ x + 75.7$
10. $y = 1.0\ x + 11.52$
11. $y = 9.28\ x + 54.8$
12. $y = 9.42\ x + 38.3$
13. $y = 11.5\ x + 3.08$
14. $y = -1.1825\ x + 22.6$
15. $y = 0.91\ x + (-35.58)$
16. $y = 2.5\ x + (-91.7)$
17. $y = -36.2\ x + 5669.95$
18. $y = 1174.9\ x + 4142$

FIGURE 21

REGRESSION EQUATIONS FOR JUNE, JULY AND AUGUST

	EQUATION
1.	$y = 22.3\ x + 5891$
2.	$y = 15.3\ x + 1934$
3.	$y = 670.8\ x + 5849$
4.	$y = 244.98\ x + 1990.6$
5.	$y = 44.3\ x + 2986.7$
6.	$y = 20.35\ x + 1743$
7.	$y =$
8.	$y =$
9.	$y = -1.65\ x + 78.7$
10.	$y = -0.02\ x + 19.5$
11.	$y = -6.77\ x + 62$
12.	$y = 2.02\ x \pm 17$
13.	$y = 1.69\ x + 10.9$
14.	$y = -0.47\ x + 13.4$
15.	$y = -0.0018\ x + 11.587$
16.	$y = 0.56\ x + (-29.3)$
17.	$y = -74.5\ x + 5853$
18.	$y = 593.6\ x\ 5188$

FIGURE 22

REGRESSION EQUATIONS FOR

APRIL, MAY AND JUNE

	EQUATION
1.	$y = 39.8\ x + 5446$
2.	$y = 61.4\ x + 1286$
3.	$y = 1124\ x + 5602$
4.	$y = 363.3\ x + 2401$
5.	$y = 28.269\ x + 4261$
6.	$y = 39.2\ x + 1491.6$
7.	$y = 1.91\ x + 6124.6$
8.	$y = -23.6\ x + 4022$
9	$y = -1.14\ x + 77.097$
10.	$y = 1.6838\ x + (-7.72)$
11.	$y = 4.78\ x + 59.68$
12.	$y = 18.7\ x + 18.8$
13.	$y = 5.596\ x + 11.8$
14.	$y = 7.398\ z + 17.5$
15.	$y = .323\ x + (-7.9)$
16.	$y = -0.04\ x + 23.6$
17.	$y = -28.04\ x + 5529.7$
18.	$y = 639.7\ x + 4918.8$

FIGURE 23

REGRESSION EQUATIONS FOR JULY AND AUGUST

	EQUATION
1.	$y = 90.99 x + 6331$
2.	$y = -14.8 x + 2847$
3.	$y = -564 x + 5710$
4.	$y = 115 x + 1908.5$
5.	$y = 61.4 x + 1782$
6.	$y = 30.6 x + 1463$
7.	
8.	
9.	$y = -2.07 x + 79.9$
10.	$y = -0.63 x + 31.1$
11.	$y = -6.49 x + 62.68$
12.	$y = 1.49 x + 13.26$
13.	$y = 4.75 x + 7.54$
14.	$y = -0.17 x + 12.9$
15.	$y = -1.056 x + 92.1$
16.	$y = -0.33 x + 38.4$
17.	$y = -131.8 x + 6231$
18.	$y = -675.98 x + 5262$

VI EFFECT OF INCINERATOR RESIDUE LEACHING ON ESTUARY QUALITY

Frequently incinerator residue is advocated for use as a construction material because of its ready availability. In regions where construction materials are at a minimum, the availability of this free construction material is quickly utilized, and the City of Philadelphia has utilized residue from their incinerators for the filling of marginal lands. Large sections of Philadelphia International Airport are city park areas are built on land which was reclaimed with incinerator residue.

The Delaware River Basin Commission has been concurrently studying the origin of oxygen demand pollutants in the Delaware estuary for approximately 10 years. This study and the development of a model was originated by the U. S. Public Health Service in the early 60's. One that has been closely scrutinized is the filling of land adjacent to the estuary with incinerator residue. Some have felt that incinerator residue could add substantially to the pollutional load in the estuary as a result of leaching action.

This phase of the study was conceived to determine the level of influence that residue might have on the pollutional load in the estuary. The initial study was a generalized estimate of the water soluble fraction which one would expect if residue was placed in an area which can be continually leached by tidal activity.

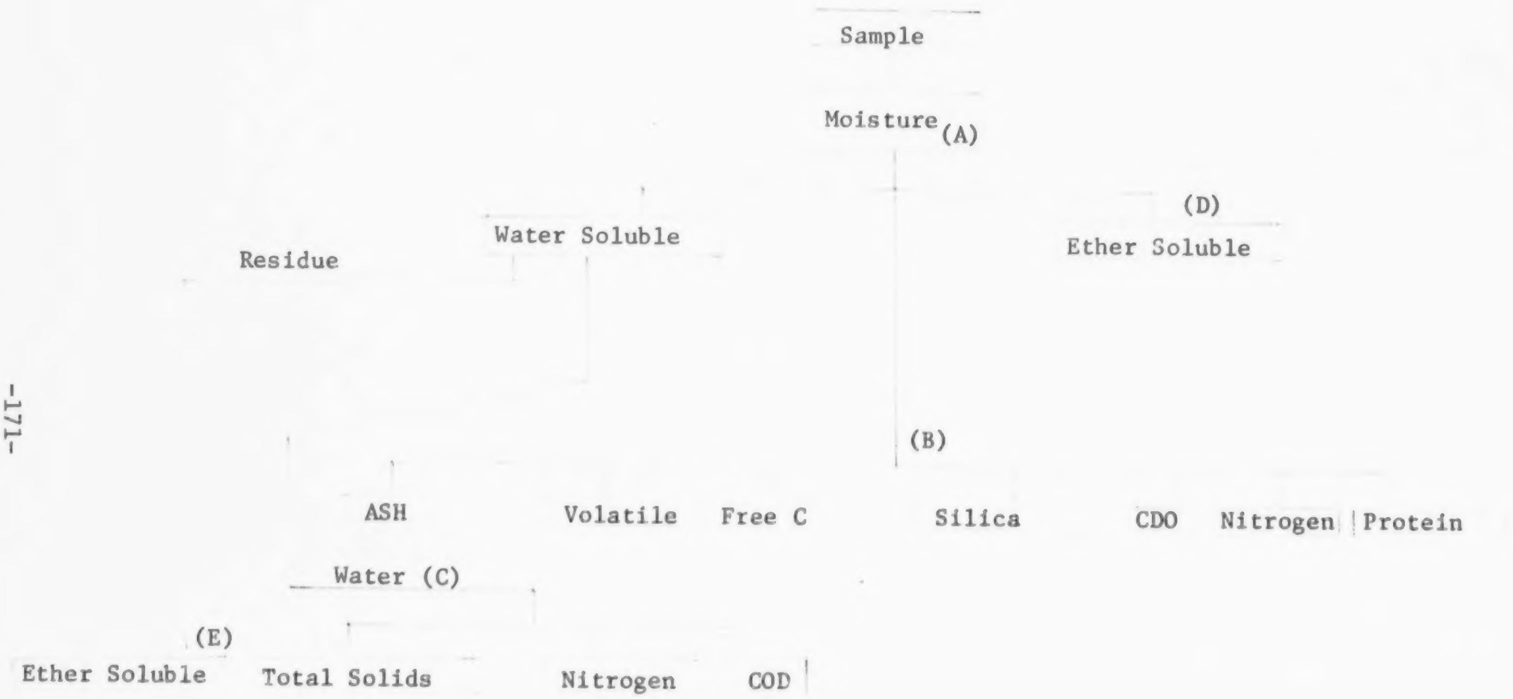
Figure VI-1 shows the analytical scheme and tests which were performed on the residue to determine its potential pollution characteristics. Residue chosen was from one of the continuous feed incinerators of the City of Philadelphia, a unit which produced a good burnout. That is to say, the amount of unburned material in the residue was at a minimum.

The first test performed was to dry the material and determine its moisture content. This was done by drying at 100°C until constant weight and the moisture content was found to be 40.93%. After determination of the moisture content, additional sample weight was dried and ground according to the sampling procedures which are described in Appendix B.

The water soluble faction was determined on a sample of residue and found to be 2.61%. The ether soluble percent was determined on the same sample and the results of four replicates are given in Table VI-1. This table represents testing level D as shown on Figure 1. At test level B chemical analyses were determined directly on the residue, and included the potential oxygen demand of the sample, nitrogen, protein, volatile fraction, ash, free carbon, silica. The results of these analyses are given in Table VI-2, and the analysis of the water soluble fraction is given in Table VI-3A.

In order to determine the overlap between the ether soluble and water soluble fractions, an ether extract was performed on the residue which had already been used for water extraction. The results of this test are given in Table VI-3. It can be seen that the water soluble fraction is much greater than the ether soluble fraction for this residue. In addition, the amount of ether soluble material is greater before leaching with water by about 15% than the soluble material after water extraction. This means that only a very small portion of the organic

FIGURE VI-1
ANALYTICAL SCHEME FOR LEACHING STUDY


Sample
Moisture (A)
Water Soluble
Residue
(D)
Ether Soluble
(B)
ASH
Volatile
Free C
Silica
CDO
Nitrogen
Protein
Water (C)
(E)
Ether Soluble
Total Solids
Nitrogen
COD

matter in residue is soluble in both petroleum ether and water. Based upon this result it can be assumed that there is very little overlap between the two fractions.

CONTINUOUS LEACHING

500 grams of residue were placed in a column and 1,000 ml of water were added daily. One liter was the total amount of water in the system which means that purging of the system was complete each day. The Kjeldahl nitrogen and COD analysis were performed on these samples for a period of 119 consecutive days. Table VI-4 shows the results of the Kjeldahl nitrogen and COD analysis with time. It can be seen that the nitrogen and COD values do fall off but at a very slow rate. After 120 days, or almost 4 months of leaching the COD of the water is still approximately 100 mg/l. The nitrogen value is still 3.5 mg/l It was assumed that stabilization of residue might occur very slowly when placed in the field.

TABLE VI-1

PERCENT PET ETHER SOLUBLE LEACHING STUDY

Test No.	Percent Soluble
1	0.701
2	0.460
3	0.755
4	0.458

TABLE VI-2

ANALYSIS OF RESIDUE IN PERCENT LEACHING STUDY

	Test No.				
	1	2	3	4	5
Chemically Decomposable Organic	413 mgO_2/gm				
Organic Nitrogen	0.116				
Protein	2.53	1.10	1.32	2.85	
Ash	88.10	86.56	87.41	89.46	87.07
Volatile	11.90	13.40	12.59	10.54	12.93
Free Carbon	3.54	5.13	5.22	5.07	5.79
Silica	66.45	66.40	62.02	64.50	64.15

TABLE VI-3

PERCENT ETHER SOLUBLE AFTER WATER EXTRACTION LEACHING STUDY

Test No.	Percent Soluble
1	0.541
2	0.604
3	0.566
4	0.630

TABLE VI- 3A

ANALYSIS OF WATER SOLUBLE FRACTION (PERCENT)
LEACHING STUDY

	TEST NO.	
	1	2
Total Solids	0.148	0.151
Volatile Total Solids	0.0294	0.0389
Kjeldahl Nitrogen	12.73 mg/l	
Chem. Oxygen Demand	768 mg/l	

TABLE VI-4
CONTINUOUS LEACHING of RESIDUE STUDY

Day	Kjeldahl N_2 in $^{mg/l}$	COD in $^{mg/l}$
1	58.38	2299
2	55.30	2223
5	50.68	2712
6	48.86	2478
7	39.34	2173
14	39.20	1702
16	41.02	855
19	40.60	1130
22	35.00	887
26	31.90	768
29	27.90	512
33	19.59	523
36	17.79	353
40	16.71	350
44	15.80	299
47	13.30	266
50	12.30	389
53	12.58	420
57	13.30	488
60	8.82	46.60
63	17.64	240
67	9.80	19.60
70	0	125
74	7.00	318
77	7.00	290
81	7.41	95.70
84	9.10	169
88	5.60	0
91	5.60	0
95	3.92	70.10
98	2.94	0
102	6.30	27.22
105	5.61	156
109	3.64	123
111	1.54	49
116	3.50	121
119	3.50	94

TABLE VI-5

RESULTS OF CHEMICAL ANALYSES

TIDAL LEACHING STUDIES

Sample	Date	pH	Alk.	NO_3	PO_4	CL^-	F^-	Ca	SO_4	Na	K	Fe	ABS	PPM	COD	N
LRA Ground	09-27-67	4.5	1158	--	3.35	875	0.00	8000	1010	760	430	1.30	0.390	0.98	67300	56.56
LRA Ground	10-11-67	6.3	6800	--	3.90	500	0.03	10666	467	605	370	2.00	0.280	0.70	33470	38.08
LRA Ground	10-25-67														19360	28.42
LRA Ground	11-10-67	28.5%	82.9%		14.1%	75%	100%	24.9%	116.2%	25.6%	16.2%	35%	39.2%	40%	8.850	19.18
LRA Ground	09-27-67	4.5	406	--	4.05	450	0.00	6000	488	415	260	1.30	0.320	0.80	55600	35.70
LRA Unground	10-11-67	5.1	2810	--	9.60	140	0.00	5000	416	230	170	2.70	0.290	0.73	20590	19.18
LRA Unground	10-25-67														8700	20.72
LRA Unground	11-10-67	11.7	855		57.8	221.4	0%	20%	17.3	80.4	52.9	518	10.3	9.5%	4020	4.34
LRB Ground	9-21-67	7.3	868	--	1.10	1112	0.02	500	374	65	360	1.30	0.240	0.60	9350	21.70
LRB Ground	10-07-67	7.9	708	--	0.50	49	0.07	733	188	230	170	2.70	0.320	0.80	7380	16.10
LRB Ground	10-20-67	8.0	458	--	5.20	90	0.01	514	294	525	78	2.00	0.200	0.50	4650	11.06
LRB Ground	10-03-67	8.7%	895		78.8	1135.5%	100%	2.7%	27.2%	87.6	361.5	35%	20%	20%	4740	10.78
LRB Unground	9-22-67	8.0	390	--	0.45	37	0.03	486	179	200	120	2.00	0.110	0.38	12090	14.42
LRB Unground	10-07-67	8.1	326	--	0.30	13	0.06	428	117	95	58	1.30	0.120	0.30	7300	10.22
LRB Unground	10-20-67	8.1	204	--	0.25	73	0.06	343	184	50	34	1.30	0.110	0.28	5650	8.68
LRB Unground	10-03-67	1.2%	91.1		80%	49.3%	50%	41.6%	2.7%	300%	253%	538%	0%	35.7%	1320	5.32

EXPANDED LYSIMETER STUDIES

Four lysimeters were constructed using 55 gallon steel drums. Six inches of Ottawa sand was placed in the bottom and incinerator residue filled to within six inches of the top. A tap with a valve was installed at the top of the bottom Ottawa sand layer. This valve was used to remove water from the tank for sampling and also for the simulation of tidal cycle.

The lysimeters were saturated with distilled water from the laboratory and allowed to sit for one week. The samples were drained and filled immediately. This sequence was followed for approximately six weeks. Table VI-3 shows the results of chemical analyses of the samples obtained from each of the four lysimeters.

Each lysimeter contained a different type of residue. Two lysimeters contained residue from the City of Philadelphia's Northeast Incinerator which is a batch feed circular hearth unit. The other two lysimeters were filled with residue from the City of Philadelphia's Northwest Incinerator which is a continuous feed chain grate incinerator. One sample from each incinerator was ground while the other two lysimeters contained unground residue. By using the ground and unground material it was hoped to determine the effect of particle size on the rate of leaching. The two residues were chosen because of their diverse characteristics. One residue contains large quantities of unburned material, while the other residue has greater burnout. The differences between the residue characteristics and the leachate characteristics from the two residues can be easily seen in Table VI.

Figure VI-2 shows the COD values for the four lysimeters. It can be seen that the COD values begin very high for the unground poorly burned refuse and for the ground well-burned residue. The drop in COD occurs very quickly and for the well burned residue the COD approaches that of domestic sewerage within the 6 weeks. This is an overall reduction in excess of 90% of total COD. In light of this it would be expected that the satisfaction of COD due to tidal leaching would occur within a relatively short period of time. These studies were carried out with one week turnover, whereas in the true tidal cycle there is a diurnal variation. However, the experimental system is somewhat different in that all lysimeters were completely drained on a weekly basis, whereas, in the tidal cycle complete draining probably does not occur.

Figure VI-3 is a similar graph for the variation of nitrogen with time. An almost idential pattern holds in that the nitrogen concentrations quickly decrease in the six week period. However, even at the end of the six weeks period the nitrogen concentration in the burned residue is still high being about 20 mg/l. This rather high concentration of nitrogen indicates that decomposition of the saturated residue occurs very slowly. The lower pH for the poorly burned residue is one reason why the organic nitrogen content is higher in that leachate than in the other leachate.

To determine some of the kinetics of oxygen uptake of residue, 500 grams of residue from the Philadelphia Northwest Incinerator were placed in 2000 mm. of distilled water. The sample was continuously aerated for 25 days. Figure VI-4 shows the oxygen uptake of the residue in this test as well as the amount of organic nitrogen present. The loss in organic nitrogen represents conversion to nitrates or total oxidation to a volatile nitrogenous product. The removal of organic nitrogen is at a much lesser rate than the uptake of oxygen. Additionally, the rate

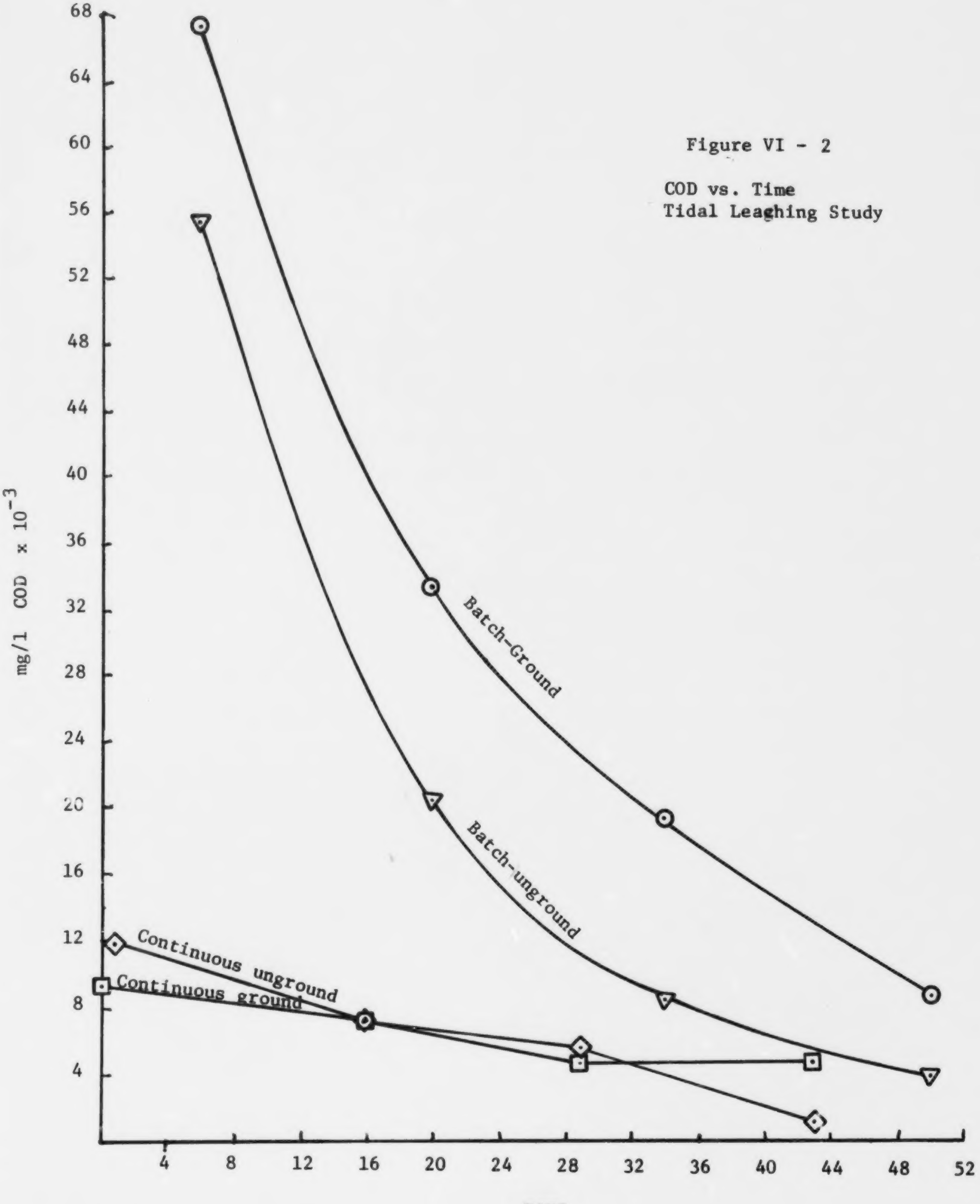


Figure VI - 2

COD vs. Time
Tidal Leaghing Study

Figure VI - 3

Nitrogen vs. Time
Tidal Leaching Study

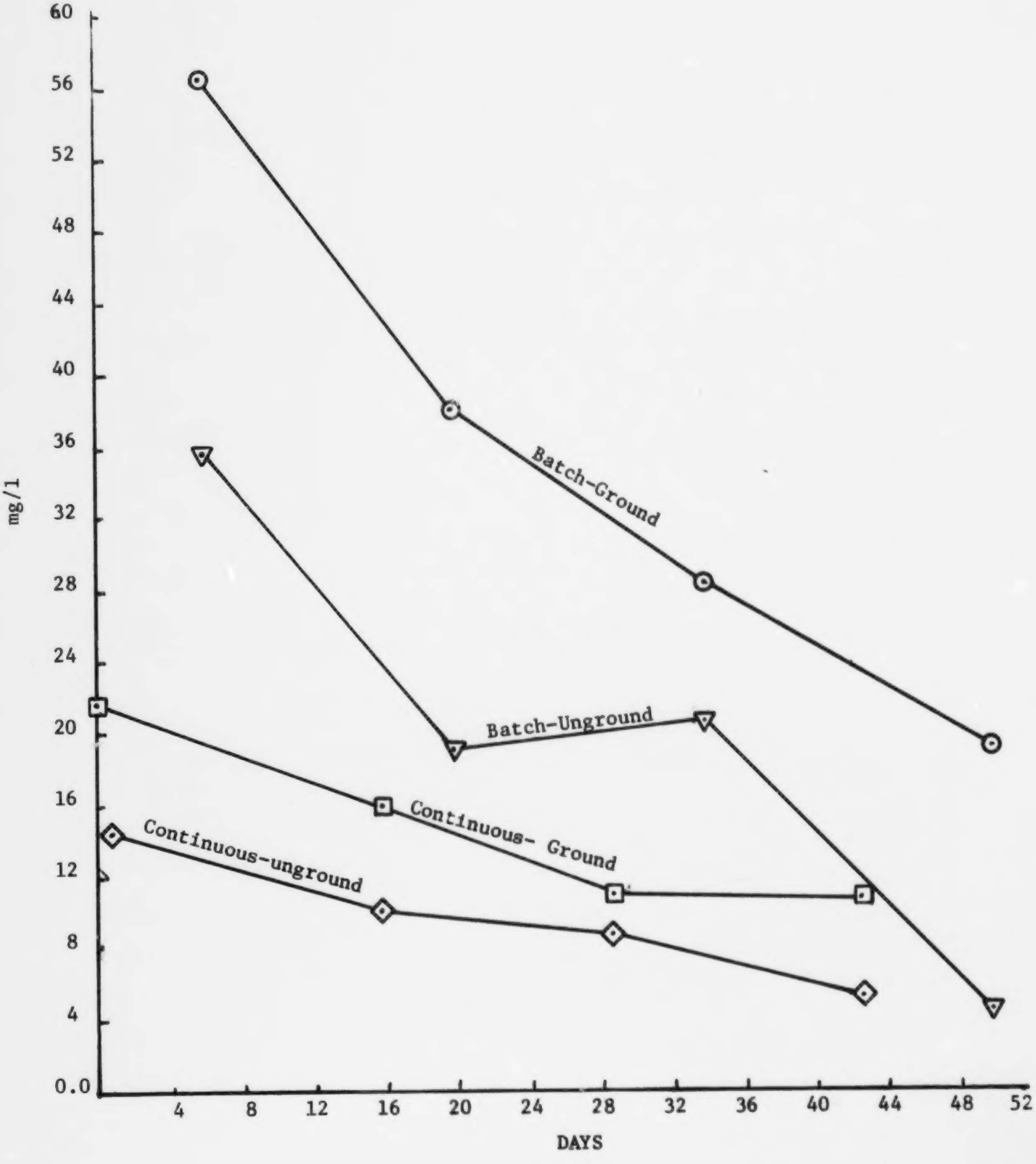


Figure VI - 4

Oxygen Uptake of Residue (unground)
Measured by CDO Test

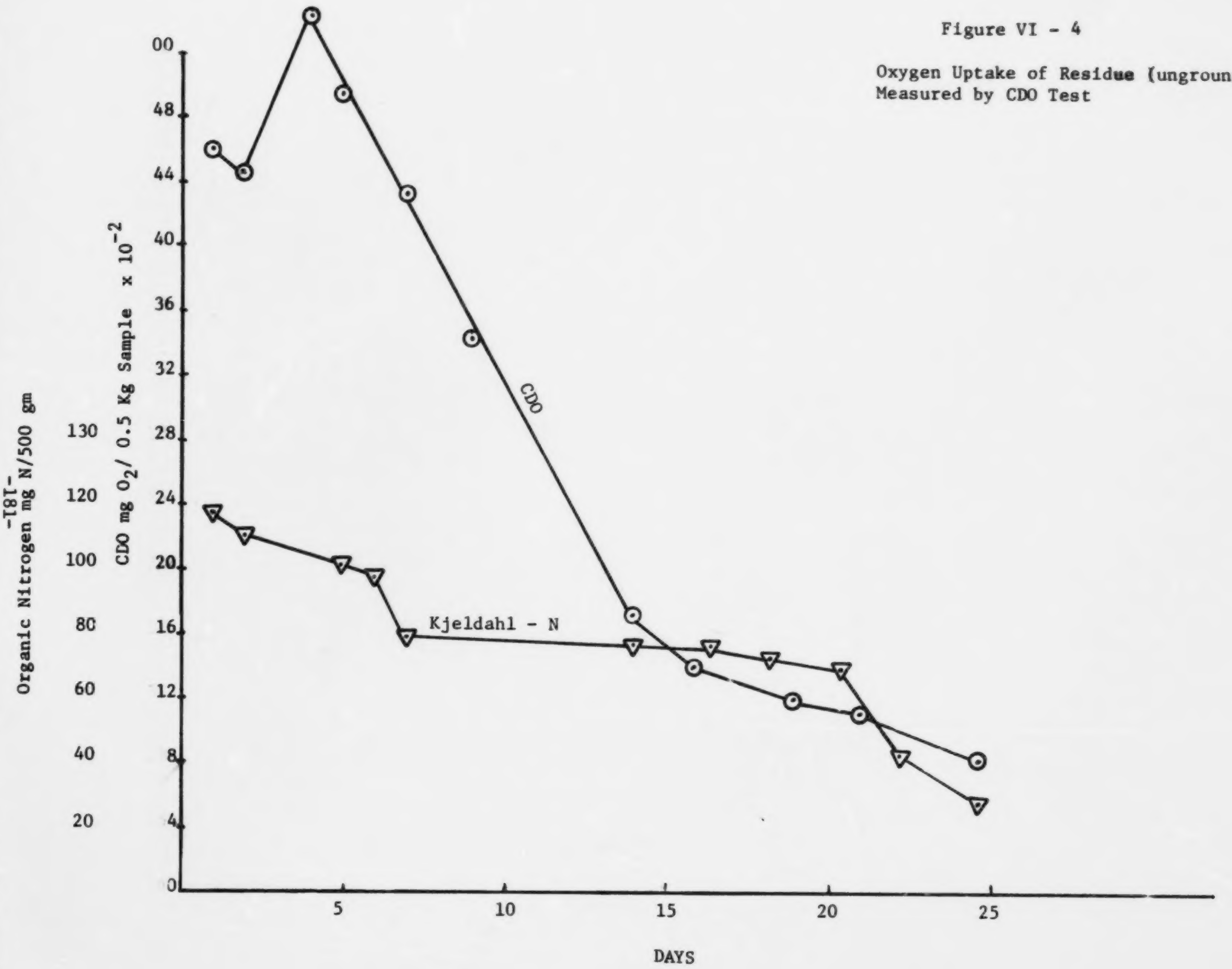


Figure VI - 5

Nitrogen and COD Variation
Simulated Tidal Cycle

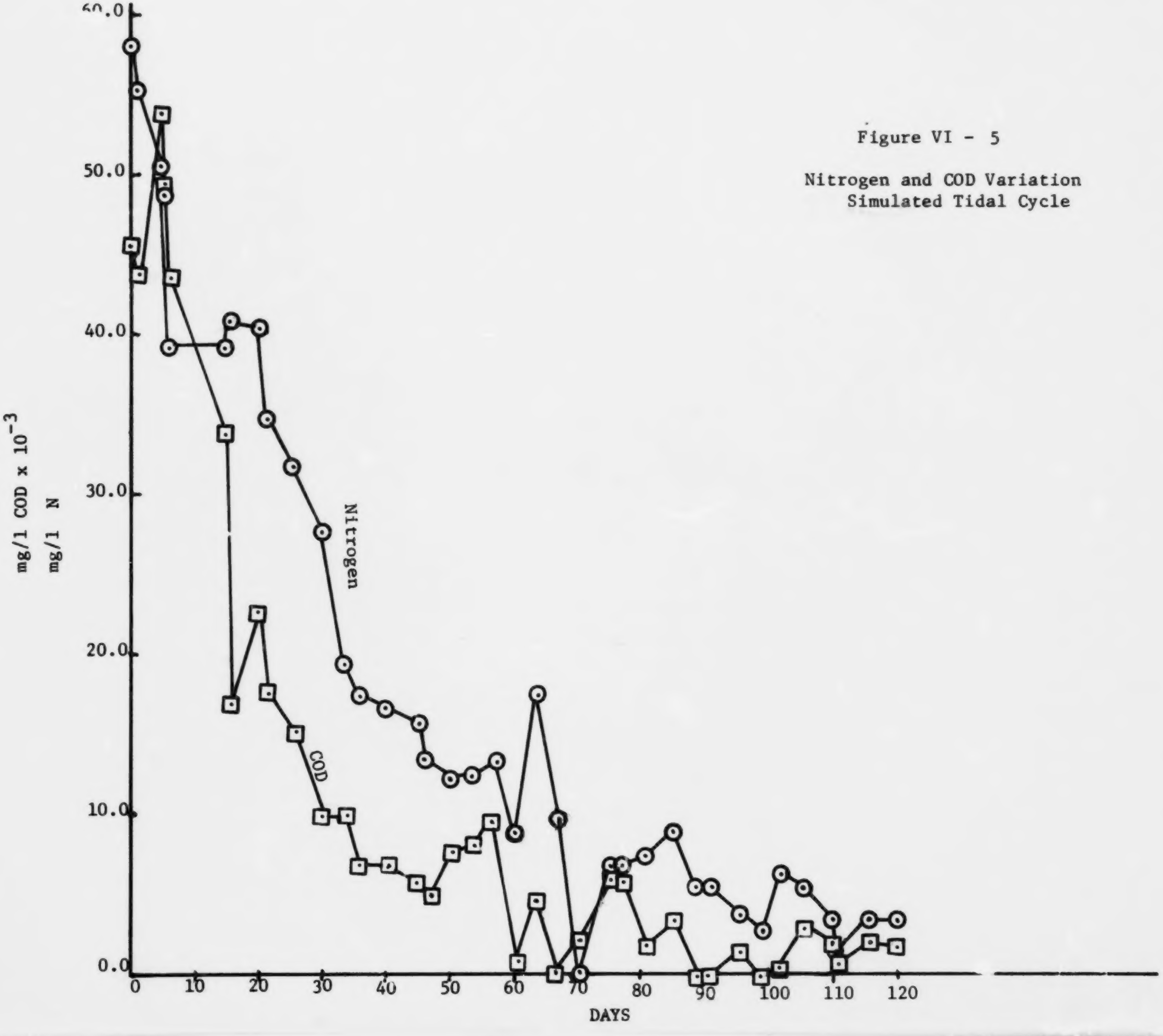
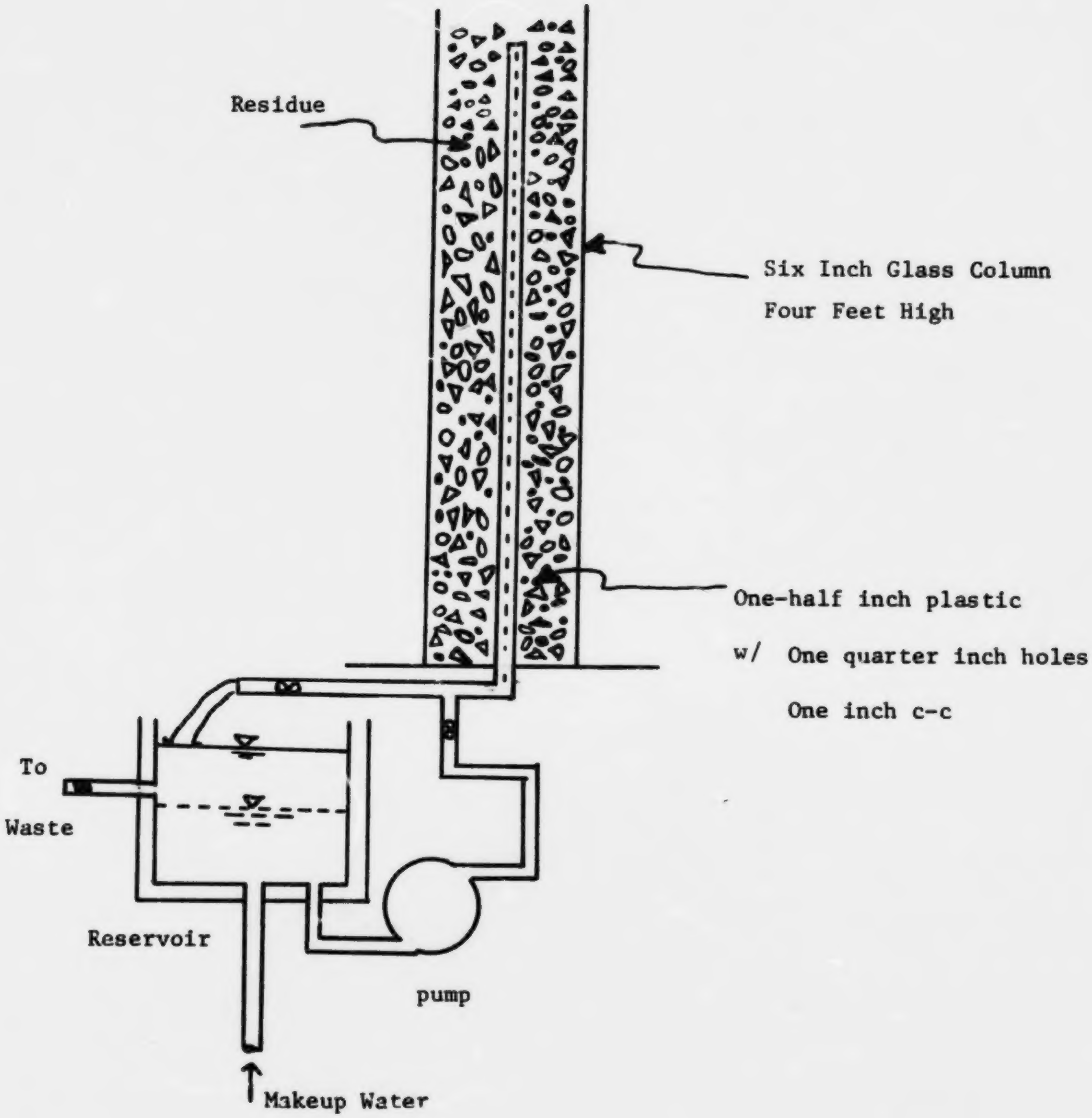


Figure No. VI - 6

Construction of Tidal Simulator


Residue
Six Inch Glass Column
Four Feet High
One-half inch plastic
w/ One quarter inch holes
One inch c-c
To
Waste
Reservoir
pump
Makeup Water

of oxygen uptake is very high initially but rapidly drops off after about two weeks. At the end of two weeks the rate of oxygen uptake decreases considerably. Table VI-6 is taken from the same data and shows the variation of pH and alkalinity over the same sample period. The pH is initially below neutral and increases rapidly for several days to be highly alkaline. Then a further dropoff of pH and stabilization occurs in the range between 7 and 7.6.

There is a total increase in alkalinity with time. This alkalinity increase represents the increasing solubility of material that has been oxidized. Some of the unburned charcoal and paper in the residue contains alkaline materials which are bound into the interstitial spaces. Until the material decomposes, these inorganic compounds will not be solublized. It should be noted that throughout the test the volume of water was maintained at 2 liters. The increase in alkalinity is the result of release of some of these compounds that have been bound into the organic matrix.

Figure VI-5 shows the variation of organic nitrogen and COD with the tidal cycle. These data were obtained from specially constructed columns which were filled with residue. These columns were constructed according to the diagram shown in Figure VI-6. This arrangement is believed to completely simulate the tidal cycle and it can be seen both the nitrogen and the COD values fall off rapidly with time. After approximately 60 days or two months the values are down to levels which can be tolerated and where the contribution to any surface water pollution would be minimal. Based upon these values it might be advisable to precondition residue which is used to fill in any tidal area.

TABLE VI-6

TIDAL LEACHING TEST

CONTINUOUS GRATE INCINERATOR

Sample #	Length Hours	pH	Total Alkalinity
1	60	6.8	62.4
2	85	7.6	69.0
3	160	8.3	92.5
4	185	7.0	99.0
5	210	7.9	75.4
6	235	6.7	105.
7	310	6.7	101.
8	335	6.3	215.
9	360	7.0	107.
10	384	6.8	110.
11	409	7.6	189.
12	505	7.0	200.
13	529	7.1	232.
14	555	6.9	215.

The City of Philadelphia is contemplating using incinerator residue as a construction material. Incinerator residue is a varying quality and the burnout is a very critical factor. If the residue is placed on the ground and allowed to cure for several months or longer, the incident rainfall will remove much of the polluting type of material. The potential polluting value of residue is so high that placement of this material should be attempted only with extreme caution. Fresh residue placed into a zone of tidal activity could cause severe oxygen sags in the vicinity of that construction area.

VII STATISTICAL PROBLEMS ENCOUNTERED IN THE ANALYSIS OF SOLID WASTE

One objective of the project is to determine the physical and chemical composition of raw refuse, incinerated residue and flyash as well as the normal variations in their composition. It is the intention here to deal with the rather unusual statistical problems which have been encountered in the data analysis.

The statistical techniques have two roles to play in the project: first, to provide confidence interval estimates of the value of the mean for each of the chemical and physical parameters of various samples of raw and incinerated refuse; second, to determine if significant differences exist between or among samples as determined by comparing the values of the mean for each of the chemical and physical parameters. Sample size for the first requirement varies directly with the level of confidence and the variation in the chemical or physical readings, and inversely with the precision or interval of the estimate; for the second requirement the size depends on the magnitude of the differences and again on the variation. Sample size, in this context, is concerned with the number of measurements or tests made on different elements of material rather than the size of the mass being measured. There was no real idea of how much variation could be expected in the readings of any of the parameters but it was certain that there would be substantial differences in the degree of variation among parameters. If the work on each of the parameters was to be handled with the same precision, then it would involve substantial differences in the sample sizes. Since it was not certain which of the parameters would prove to be of greatest interest, it was decided to work initially with a fixed sample size and then refine the procedures further as more information was obtained.

Sampling Procedure

Because of the heterogeneous nature of both raw and incinerated refuse, it would be necessary to chemically analyze a sample element consisting of hundreds of pounds of material in order to guarantee that the sample element was representative of the entire mass. Because of the presence of bulk items such as bricks, glass, cans, and certain industrial refuse, the use of smaller weights of material would introduce very large variations between sample elements and seriously restrict the sensitivity of the experiment. On the other hand, the chemical analyses performed are of such a complicated and sensitive nature that quantities in the order of 2 to 25 grams of material are about as large as can be practically handled. In other words, it was impossible, in its present state, to obtain homogeneity within any representative sample element which was sized to make chemical analysis feasible. To overcome this problem, it was necessary to develop a procedure which would process a representative sample in order to minimize its heterogeneous nature by mechanical breakdown of bulk items and then uniformly mix the ingredients. A procedure, developed in this project and given in the Appendix attempts to obtain small sample elements which are fairly representative of a heterogenous mass.

SAMPLE PROCEDURE-REFUSE

A maximum of about one and a half days' supply or 900 tons of raw refuse can be stored in the two sectioned pit before each unit, but actually about one-half of this is available at any one time. An overhead crane, which is used for charging, tosses and mixes the material in the pit and then removes and places one bucketful (1800-2000 pounds) on the ground. From this mass, a hand selected and theoretically unbiased sample of 500 pounds is selected for further processing through a hammer mill where it is reduced in size to approximately ½ inch or less. This processing includes bulk items such as glass, cans, bricks, wood, cloth and paper which can pick up moisture and organic materials on their surfaces during the mixing process, and their removal could bias the sample. From the rough ground mass, about 100 pounds is selected for final grinding (less than No. 10 mesh) through a small laboratory mill. Samples for processing of residue are handled in a similar manner.

Samples for the chemical analysis of either raw or incinerated refuse are drawn from the final ground mass. It was apparent that the particle size of the final ground material was not completely uniform and still consisted of some lumps of material mixed with even finer sized particles. The sample element is so small that a lump might constitute a fair portion of a sample element or a lump could be completely ignored. Undoubtedly, the method of drawing such small sample elements could be biased in the direction of selecting the finer material.

Initially, it was determined that a sample of five elements would be used for each chemical test, and, since the tests are destructive, this could entail a total of 140 elements all drawn from the same 100 pounds of processed refuse. Five tests is the minimum that could reasonably be used for statistical testing, but it should be recognized that these were pilot samples, and the sample size requirements for certain parameters could be revised upward where greater sensitivity, or greater variation, indicated that it was advisable.

Method of Analysis

For each parameter the results of several samples, drawn from several days, were recorded using five test runs per sample. The standard analysis of variance model was used to determine if there were significant differences amongst these samples. This model is based on the hypothesis that the means of the several samples are drawn from the same population and any actual differences which exist must be due to sampling variation. The degree of sampling variation which could be reasonably expected is a function of the internal variation found within the samples. By comparing the variation amongst the various sample means to the pooled variation within the samples, it is possible to determine whether significant differences amongst the samples exist.

Where there are significant differences among the means, two components of variation can be determined within this same mathematical model. The first component is based on the pooling and weighting of the variation within the several samples (the variation amongst the five sample elements for each of the several samples). This component can be considered as being due to the measuring technique, chemical analysis variations and lack of homogeneity of the processed sample. This component is translated into the units of the parameter being measured and called "Significant Difference Experimental." It represents the difference between samples which can be detected with the present measuring system based on samples of five elements and any lesser differences could be due to random variation. The other component of interest is based on the pooled internal variation within the several samples as well as the variation between samples. It treats all the data as if it were one large sample. This component can be considered as being due to the measuring technique, chemical analysis variation, lack of sample homogeneity, as well as the day-to-day variations. When translated into units of the parameter, it was called "Significant Difference Total" and represents the differences between samples which can be detected with the present measuring system based on samples of five elements. Any lesser differences could be due to random variation.

These same significant differences were used to establish two types of confidence interval estimates for each of the means of the several parameters. Adding and subtracting the "Significant Difference Total" to the grand mean of all samples yields a wider confidence interval than "Significant Difference Experimental." This wider interval would more correctly represent the over-all composition over a period of time where no alteration in method is affected.

In order to evaluate certain of the chemical procedures in the analysis, "knowns" where available, were obtained and samples of five elements were tested using the same method of analysis as with the refuse. The variations of the five sample elements from "knowns" were compared to the corresponding "Significant Difference Experimental" in order to break down this component. The variation in the knowns would be due to the measuring technique and chemical analyst's variations, and any further variation present in the "Significant Difference Experimental" would be due to the lack of homogeneity of the processed refuse.

Results in General

The results of the analysis for flyash, residue and refuse are summarized in the attached three tables and an explanation of terms precedes the tables. All of the results tabulated here were collected from the Northwest Incinerator, although a considerable amount of analysis has been done with materials from incinerators at: Northeast Philadelphia;

Delaware County; Philadelphia East Central; Atlanta, Georgia (old and new installation); Philadelphia Harrowgate; Louisville, Kentucky; and Miami, Florida. A blank column indicates that no samples were analyzed in this case.

Since, for a large part, the validity of this data depends on the success of the sampling procedure, it would be well to consider the results of the tests on the "knowns". There were limitations on what "knowns" could be obtained, but the results of their analyses would seem to indicate that the sample material was reasonably homogeneous since none of the comparisons of the results of the "knowns" with the "Significant Difference Experimental" gave any indications that there were significant differences. Whether it could be a problem with the parameters for which "knowns" were not available cannot be determined, but it is not unreasonable to conclude that if this were a problem, it would have shown up in the parameters which could be checked.

As expected, there were varying degrees of variation encountered amongst the various parameters. The varying degrees of variation were due, somewhat, to the percentage concentration of the chemical component. If it were present in high concentrations, then it would be reasonable to expect wider variations from sample element to sample element and from day to day. But even so, there were certain test results which had greater or less variation than could be attributed to concentration.

In all cases, there were significant differences amongst the several samples (different days) than could be attributed to the sampling variation. In other words, there was more variation in day to day operation than was experienced in the analysis of a single day's material. This means that the "Significant Difference Total" would have to be used to determine any differences in the operation of a single incinerator or when comparing different incinerators. Naturally, the sensitivity is reduced as a result.

The raw and incinerated refuse of several incinerators is compared on the basis of each of the parameters. Differences in some of the parameters were noted, but in other cases no significant differences were indicated. The failure to detect differences may not mean that there actually aren't differences present, but may be a lack in sensitivity of the test. For some parameters, the day to day variations present in the same incinerator are too large to detect small differences between incinerators. Where necessary we can compensate for this by increased sample sizes.

Explanation of Terms Used in Attached Tables

Mean: This is the collective average of all readings - multiple as well as single samples.

No. of Samples: This is the number of samples analyzed, each sample drawn from different masses of material processed on different days.

Total No. of Readings: This is the combined total of all readings made from all samples, ideally five per sample but probably less due to measurement problems or limitations.

Std. Dev. Experimental: This is the standard deviation based on the internal variations in the multiple samples and does not include the components due to variations between samples. The internal variations could be considered as being due to experimental measurement variations as well as lack of homogeneity within the several samples. If we consider multiple sample as homogeneous, then this can be considered as the variation due to the measuring technique.

Std. Dev. Total: This is the standard deviation based on the internal variation in the multiple sample as well as the variation between samples. This treats the data as if it were one large sample. It includes the experimental variation, as well as that due to the heterogeneous nature of the material and the day-to-day variations.

Where blank, data on only one sample was available so that no estimate of day-to-day variations was possible.

Sig. Diff. Exp.: This is the difference which you can expect to detect, based on the present measuring system, the heterogeneous nature of the samples themselves and using a sample consisting of five readings. Any lesser differences could be due to random variation.

Sig. Diff. Total: This is the difference which you can expect to detect, based on the present measuring system, the heterogeneous nature of the sample, the day-to-day variations, and using a sample consisting of five readings. Any lesser differences could be due to random variation.

Where blank, data on only one sample was available and no estimate could be made.

Sig. Diff. Among All Samples: This is based on the standard analysis of variance where "yes" means that there was a significant difference (.05 level) among the various sample means based on the internal variation within the sample. "No" means that the data did not indicate that there was a significant difference. (The differences which exist could be due to sampling variations.)

TABLE VII - 1
*SUMMARY OF RESULTS - Flyash

	Moisture 70° C %	Moisture 110° C %	Xylene %	Pot. Oxide %	Ash %	Volatile %	H_2O Sol. %	Pet. Ether %	Benzene %	Free Carbon %
Mean all Samples	0.27	.36			93	7	4.12	-		8.01
No. of Samples	1	1			1	1	1	1		1
Total No. Readings	5	4			5	5	4	4		5
Std. Dev. Exper.	.09	.01			1.74	1.74	3.01	.43		1.22
Std. Dev. Total	-	-			-	-	-	-		-
Sig. Diff. Exper.	.12	.01			2.16	2.16	3.73	.53		1.51
Sig. Diff. Total										
Sig. Diff. Among all samples										

	Silica %	Kjeldahl Nitrogen %	Sulfur %	Iron (Polar) %	Carbon %	Hydrogen %	Lead %	Tin %	Zinc %	Beta Rad. m.r.	Cellulose %
Mean all Samples	66.19		.01	4.73	12.63	.39	3.94				
No. of Samples	1		1	1	1	1	1				
Total No. Readings	4		3	5	3	3	5				
Std. Dev. Exper.	6.61		0.00	.39	.49	.10	.18				
Std. Dev. Total	-		-	-	-	-	-				
Sig. Diff. Exper.	8.20		0.00	.48	.61	.12	.22				

	Calorific Value BTU/1b	Carbohydrate %	Protein %	Phosphorus Oxide %	Iron (Color) %	Sodium %	Potassium %	
Mean all Samples	1365.33							
No. of Samples	1							
Total No. Readings	3							
Std. Dev. Exper.	178.61							
Std. Dev. Total	-							
Sig. Diff. Exper.	221.48							
Sig. Diff. Total								
Sig. Diff. Among all Samples								

*Source - Philadelphia Northwest Incinerator

TABLE VII - 2

*SUMMARY OF RESULTS - Residue (burned)

	Moisture 70°C %	Moisture 110°C %	Xylene %	Pot. Oxide %	Ash %	Volatile %	H_2O Sol. %	Pet. Ether %	Benzene %	Free Carbon %
Mean all Samples	14.61	14.82	17.72	.96	81.26	18.72	4.48	2.97	3.37	9.89
No. of Samples	28	30	20	7	43	43	27	41	11	28
Total No. Readings	134	124	68	14	161	161	107	145	40	93
Std. Dev. Exper.	1.77	1.77	1.60	.32	3.36	3.30	1.55	1.01	.58	2.84
Std. Dev. Total	7.52	7.54	8.48	.64	11.04	11.00	5.98	5.19	8.01	7.69
Sig. Diff. Exper.	2.20	2.20	1.98	.40	4.17	4.09	1.92	1.25	.72	3.52
Sig. Diff. Total	9.33	9.35	10.52	.79	13.69	13.64	7.42	6.44	9.93	9.54
Sig. Diff. Among	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

	Silica %	Kjeldahl Nitrogen %	Sulfur %	Iron (Polar) %	Carbon %	Hydrogen %	Lead %	Tin %	Zinc %	Beta Rad. m.r.	Cellulose %
Mean all Samples	60.39	.05	.07	12.17	6.20	.43					
No. of Samples	25	1	22	26	20	20					
Total No. Readings	110	2	60	110	76	75					
Std. Dev. Exper.	4.35	0.00	.03	4.90	1.77	.22					
Std. Dev. Total	20.83	---	.08	6.50	5.11	.27					
Sig. Diff. Exper.	5.39	0.00	.04	6.08	2.20	.27					
Sig. Diff. Total	25.83	---	.10	8.06	6.34	.34					
Sig. Diff. Among all Samples	Yes	---	Yes	Yes	Yes	Yes					

	Calorific Value BTU/lb	Carbohydrate %	Protein %	Phosphorus Oxide %	Iron (Color) %	Sodium %	Potassium %
Mean all Samples	2187.56	65.23	.21	.02	12.23	0.00	.01
No. of Samples	20	9	8	9	8	5	8
Total No. Readings	59	33	22	35	40	10	25
Std. Dev. Exper.	489.90	8.77	.05	--	4.80	--	--
Std. Dev. Total	1000.00	209.05	.41	--	6.97	--	--
Sig. Diff. Exper.	607.48	10.88	.06	--	5.95	--	--
Sig. Diff. Total	1240.00	259.22	.51	--	8.64	--	--
Sig. Diff. Among all Samples	Yes	Yes	Yes	Yes	Yes	No	No

*Source - Philadelphia Northwest Incinerator

TABLE VII - 3
*SUMMARY OF RESULTS - Refuse (unburned)

	Moisture 70°C %	Moisture 110°C %	Xylene %	Pot. Oxide %	Ash %	Volatile %	H_2O Sol. %	Pet. Ether %	Benzene %	Free Carbon %
Mean all Samples	13.00	13.00	16.07	--	41.72	58.16	6.02	4.02	3.60	22.55
No. of Samples	18	14	16		18	18	17	18	5	12
Total No. Readings	88	88	56		85	85	81	88	24	55
Std. Dev. Exper.	1.76	1.76	3.17		5.49	5.48	1.31	1.26	.72	5.96
Std. Dev. Total	6.36	6.36	9.15		19.15	19.18	3.08	1.90	4.11	11.48
Sig. Diff. Exper.	2.18	2.18	3.93		6.81	6.80	1.62	1.56	.89	7.39
Sig. Diff. Total	7.89	7.89	11.35		23.75	23.78	3.82	2.35	5.10	14.24
Sig. Diff. Among all Samples	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes

	Silica %	Kjeldahl Nitrogen %	Sulfur %	Iron (Polar) %	Carbon %	Hydrogen %	Lead %	Tin %	Zinc %	Beta Rad. m.r.	Cellulose %
Mean all Samples	26.03		.14	7.18	30.24	4.53					14.69
No. of Samples	13		17	9	18	18					3
Total No. Readings	59		51	43	65	65					8
Std. Dev. Exper.	4.28		.11	5.82	3.34	.54					1.76
Std. Dev. Total	13.45		.18	8.42	2.58	1.37					9.00
Sig. Diff. Exper.	5.31		.14	7.22	4.14	.67					2.18
Sig. Diff. Total	16.68		.22	10.22	3.20	1.70					11.16
Sig. Diff. Among all Samples	Yes		Yes	Yes	Yes	Yes					Yes

	Calorific Value BTU/lb	Carbohydrate %	Protein %	Phosphorus Oxide %	Iron (Color) %	Sodium %	Potassium %	
Mean all Samples	5059.62	.09	1.29		4.84			
No. of Samples	18	9	6		9			
Total No. Readings	55	38	16		43			
Std. Dev. Exper.	894.43		.25		2.70			
Std. Dev. Total	2236.07	.04	.95		4.91			
Sig. Diff. Exper.	1109.09		.31		3.35			
Sig. Diff. Total	2772.73	.05	1.18		6.09			
Sig. Diff. Among all Samples	Yes	Yes	Yes		Yes			

*Source - Philadelphia Northwest Incinerator

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APPENDIX A

METHODS OF ANALYSES

MODIFIED PROXIMATE ANALYSIS

The modified proximate analysis includes the determination of moisture, ash, combustible, free carbon and silica. The silica fraction is not totally silicon compounds, but rather is a combination of insoluble oxides of many materials. Silicon compounds are the primary constituent. Determination of the moisture content is described only for the drying technique. The Karl Fischer and Xylene extraction methods are described elsewhere in this appendix.

Sample Size:

A. 25 Grams Residue

B. 5 Grams Refuse

Procedure:

A. Moisture:

1. Place sample into previously conditioned and weighed crucible. Weigh sample plus crucible.
2. Dry at $101^{\circ} - 103^{\circ}$ C. until constant weight is reached.
3. Allow to cool in a desiccator until room temperature is reached and accurately weigh the sample and crucible.
4. Calculations:

$$\frac{\text{Initial Wt.} - \text{Dry Wt.}}{\text{Initial Wt.}} \times 100 = \text{Percent Moisture}$$

B. Combustible and Ash:

1. Place crucible and sample in a muffle furnace for three hours at 750°C.
2. Cool five minutes in the atmosphere and then cool 30 minutes in a desiccator.

3. Calculations:

a. $$\frac{\text{Final Weight}}{\text{Initial Weight}} \times 100 = \text{Percent Ash}$$

b. $$\frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100 = \text{Percent Volatile}$$

C. Acid Weight:

1. Place a dried sample of either the refuse or residue in a 250 ml. beaker.

2, Add 50 ml. aqua regia and heat on a hot plate for about three hours under a hood.

3. Cool to room temperature and transfer the digested sample to centrifuge tubes. Centrifuge for one hour at 15,000 rpm.

4. Filter the sample through a pre-weighed filter paper (Whatman No. 1). Save filtrate for iron analysis.

5. Dry the sample and filter paper in a previously conditioned crucible. Cool to room temperature and weigh. The sample weight after drying is called the acid weight.

D. Free Carbon and Silica:

1. Place the acid sample in a muffle furnace at 750°C. for three hours. Allow to cool and weigh at room temperature.

2. Calculations:

a. $$\frac{\text{Final Muffled Acid Wt.} - \text{Crucible Wt.}}{\text{Initial Dry Wt.}} \times 100 = \text{Percent Silica}$$

b. $$\frac{\text{Initial Acid Wt.} - \text{Final Muffled Wt.}}{\text{Initial Acid Wt.}} \times 100 = \text{Percent Free Carbon}$$

PERCENT WATER SOLUBLE

The water soluble fraction is used as an indicator of the percent of residue or refuse which can be immediately leached from a landfill. It is necessary to analyze the water soluble fraction, thus, a large sample must be taken in order that two liters of solution are obtained.

Procedure:

A. Weigh 250 grams of residue or 250 grams of raw refuse which has been dried at 70°C.

B. Add 2000 ml of distilled water and stir continuously for eight hours.

C. Filter the sample in a large Buchner funnel on to a glass mat. Press the sample to remove as much water as possible.

D. Wash with 1000 ml of water and press again.

E. Repeat D one more time.

F. Dry the solid sample and calculate the water soluble percentage.

G. Save the filtrate for analysis.

Calculation:

$$\text{Percent Water Soluble} = \frac{\text{Initial Dry Wt.} - \text{Final Wt.} \times 100}{\text{Initial Wt.}}$$

ETHER SOLUBLE FRACTION

The fraction of the material which is soluble in petroleum ether will include many organic compounds as well as some inorganic substances. On occasion this fraction has been referred to as the lipid fraction.

Procedure:

A. Dry, cool, and weigh a paper extraction thimble stoppered with a small amount of glass wool. Add approximately two to three grams of the sample prepared as directed under Sample Preparation.

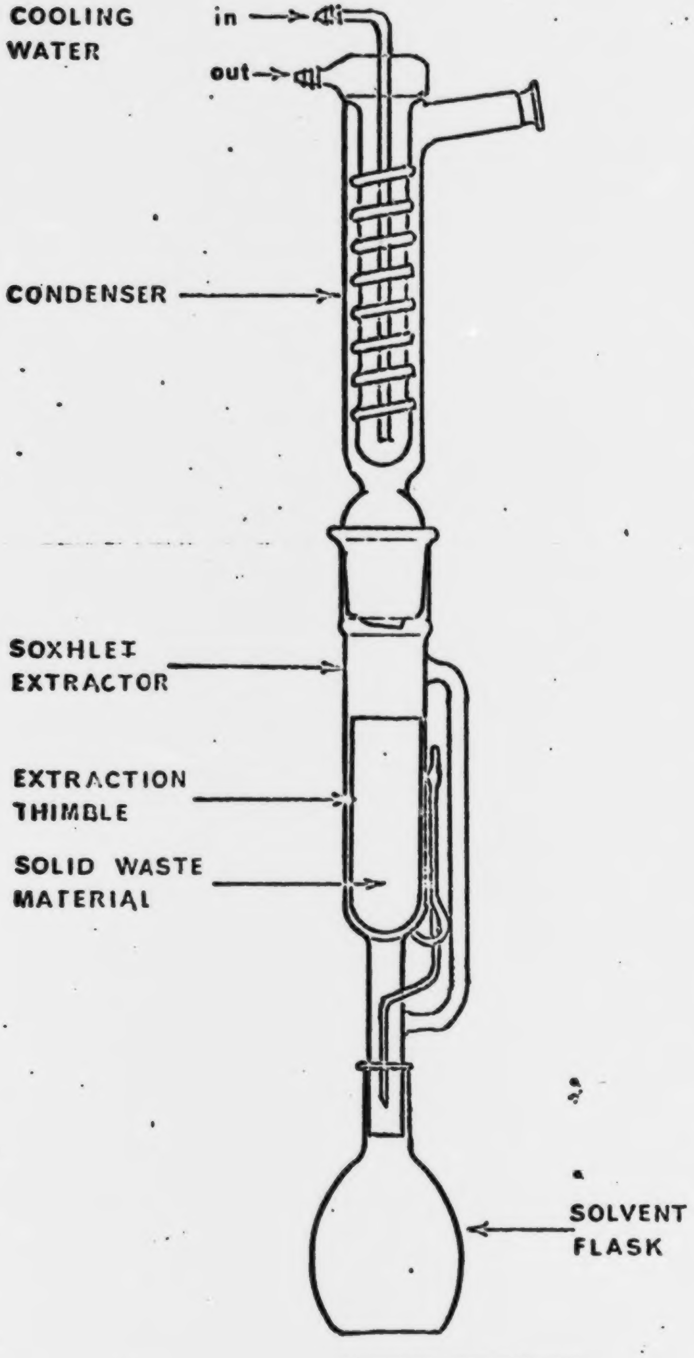
B. Dry in the 70°C oven for two hours or until constant weight, cool in a desiccator and weigh. The difference in weight is the weight of the sample.

C. Place extraction thimble in a Soxhlet Extraction Apparatus, Figure A - 1, and extract lipids using petroleum ether (BP 65° - 67°C) at a rate of approximately 10 cycles per hour for three hours.

D. Dry extraction thimble and contents at 70°C for about two hours. Cool in a desiccator and weigh. The difference in weight before and after extraction with petroleum ether is the weight of the lipids.

Calculations:

$$\text{Percent Lipids} = \frac{\text{Loss of Weight (grams)} \times 100}{\text{Weight of Sample (grams)}}$$


COOLING WATER
in
out
CONDENSER
SOXHLET EXTRACTOR
EXTRACTION THIMBLE
SOLID WASTE MATERIAL
SOLVENT FLASK

SOXHLET EXTRACTOR

FIGURE A - 1

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CHEMICAL DECOMPOSABLE ORGANIC (CDO)

Chemical Decomposable Organic is determined by disgesting the solid sample in a mixture of potassium dichromate and concentrated sulfuric acid. The excess potassium dichromate is determined by titrating with ferrous ammonium sulfate.

Apparatus:

A. 500 ml Erlenmeyer flasks with 24/40 joint.

B. Reflux condenser with 24/40 joint.

C. Hot plate.

D. Rubber tubing.

E. 50 ml burets.

Reagents:

A. 0.500 N Potassium Dichromate Standard: Dissolve 24.518 grams of Primary Standard Potassium Dichromate in distilled water and dilute to 800 ml. Add 0.12 gram of sulfuric acid and dilute to one liter.

B. Sulfuric Acid: Dissolve 22 grams of silver sulfate in nine pounds of concentrated sulfuric acid.

C. 0.250 N Ferrous Ammonium Sulfate Standard: Dissolve 98 grams of ferrous ammonium sulfate in distilled water. Add 20 ml of concentrated sulfuric acid, cool and dilute to one liter. (The ferrous ammonium sulfate must be standarized daily against the dichromate solution.)

D. Ferrion Indicator: Dissolve 1.485 grams of 1,10 phenathroline monmhydrate together with 0.695 grams of ferrous sulfate in water and dilute to 100 ml.

Standardization:

Dilute 5.00 ml of standard potassium dichromate to about 100 ml. Add 30 ml of concentrated sulfuric acid and cool. Add several drops of ferrion indicator and titrate with ferrous ammonium sulfate until a pink endpoint is reached. The milli-equivalents of iron (++) will equal the milli-equivalents of dichromate (=)

$$N\ (Fe^{++}) \times ml\ (Fe^{++}) = N\ (\text{Dichromate}\ =) \times ml\ (=)$$

Procedure:

A. Weigh accurately about 1.0 gram of solid sample and place in an Erlenmeyer flask. Add 50 to 100 ml of distilled water along with 0.1 fram of mercuric sulfate. Add 25 ml of the dichromate solution. Place several glass beads in the flask and very carefully add about 75 ml of sulfuric acid reagent. (Mix all contents thoroughly. Exercise extreme caution.)

B. Each sample is to be performed in triplicate and one blank should be run concurrently.

C. Reflux for two hours and then allow the mixture to cool. Wash the condensers with distilled water and add the washings to the flask.

D. Dilute the mixture to about 300 ml.

E. Add several drops of ferrion indicator and titrate to the endpoint.

Calculations:

A. Milli-equivalents Organic = Milli-equivalents Dichromate = Milli-equivalents Oxygen

B. 1 ml of 1.0 N Potassium Dichromate = 8 mg Oxygen

C. (A) equals ml dichromate used for sample
(B) equals total ml of dichromate for blank

1. Milli-equivalents Dichromate Used = (B - A) ml x N (Fe^{++})

2. Mg Oxygen = (B - A) ml x N (Fe^{++}) Milli-equivalents Dichromate x 8

3. $$\frac{\text{Mg O}}{\text{Gram Sample}} \qquad \frac{(B - A)\ N\ (Fe\ \ ) \times 8}{\text{Grams of Sample}}$$

UNIT WEIGHT (Unground)

Unit weight of raw refuse or incinerated residue is required for the design of vehicles, storage pits, transfer trucks, and for estimating the amount of refuse which is burned in plants which do not have a scale. Many variations of unit weight are used for sand, gravel, soil, coal, and other solid materials. The picture shown as Figure A-2 depicts the apparatus which is used in the analysis of unit weight.

Procedure:

A. The bottom hopper door should be latched before the frest sample is introduced into the hopper.

B. The volumetrically calibrated clean receiver is placed on the balance and its tare weight set on the tare beam.

C. The receiver is then placed directly beneath the hopper.

D. The hopper door is unlatched and allowed to swing freely open.

E. The sample is allowed to fill the basket to overflowing. If the sample does not fall freely with the hopper door open, the sides of the hopper can be tapped with the scraping rod.

F. The scraping rod is run one time across the receiver top to level the waste. For raw refuse it may be necessary to manually balance the surface voids.

G. The receiver and sample are placed on the balance, and the weight of the sample to the nearest 0.020 kg is recorded as "W".

Calculations:

A. $$\frac{\text{Weight of Solid Waste}}{\text{Receiver Volume}} = \text{Unit Weight "As Received"}$$

B. $$\frac{\text{Weight of Sample} - \text{Weight of Moisture}}{\text{Receiver Volume}} = \text{Dry Unit Weight}$$

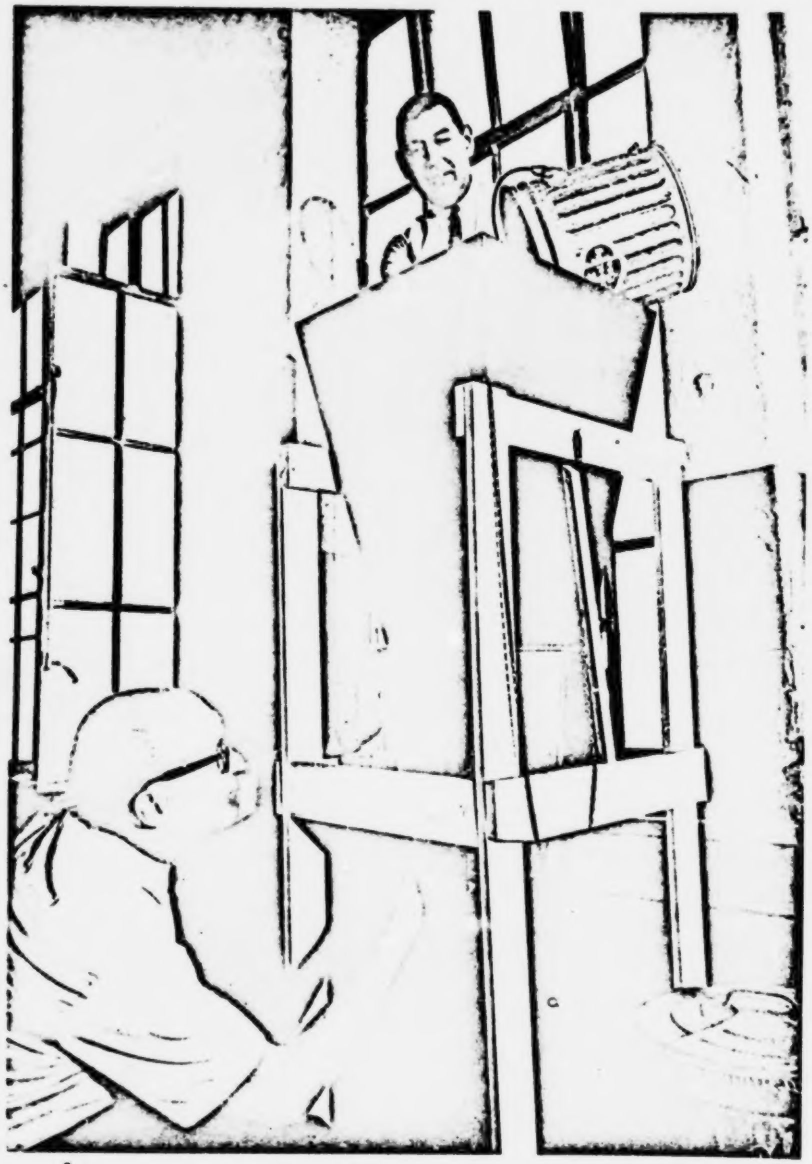


FIGURE A-2

UNIT WEIGHT APPARATUS

UNIT WEIGHT (Ground)

The unit weight of ground solid waste material is of use in predicting the degree of compaction and landfill volume required for disposal. At the present time not many landfills grind the waste prior to ultimate disposal, however, it is expected that this practice will increase. The key to rail - haul systems is grinding the baling of the waste before disposal.

Procedure:

A. Obtain tare weight of the 1/3 cubic foot measure.

B. The measure is filled one-third and the top leveled off.

C. The sample is rodded with the hemispherical end of the tamping rod for 25 strokes, evenly distributed over the surface.

D. The measure is filled two-thirds full and again rodded with 25 strokes as before. Only enough force shall be used to penetrate the second layer.

E. The measure is then filled to overflowing and rodded 25 times as before. Only enough force shall be used to penetrate the third layer.

F. Surplus sample is to be struck off using the tamping rod as a straight edge and the top leveled as nearly as possible.

G. The measure and its contents are weighed to the nearest tenth of a gram and recorded as "W".

Calculations:

$$\frac{\text{Weight of Sample}}{\text{Volume of Measure}} = \text{Unit Weight (Ground)}$$

APPARENT SPECIFIC GRAVITY

Apparent specific gravity is an indicator of the physical characteristics of refuse and residue in water. The method which is presented was modified to use paraffin oil in lieu of water for the procedure. Refuse and residue can absorb large quantities of water, but a negligible amount of paraffin oil will be absorbed.

Apparatus:

A. Calibrated Volumetric Container (500 ml)

B. Paraffin Oil

Procedure:

A. The clean, dry volumetric container shall be weighed to the nearest hundredth of a gram, and the weight recorded as "b".

B. Approximately 50 grams of ground raw refuse or 200 grams of ground residue are weighed to the nearest hundredth of a gram, and the weight recorded as "r".

C. The sample is then introduced into the container and enough paraffin oil is added to just cover the surface of the sample.

D. The aggregate is stirred with a glass stirring rod so that the oil throughly permeates the sample. The stirring rod and the sides of the container are rinsed with paraffin oil of any adhering sample.

E. Additional paraffin oil is then added to approximately the 450 ml mark and the assembly permitted to sit motionless for 30 minutes.

F. Additional paraffin oil is introduced by means of a pipet until the level of the oil is exactly 500 ml.

G. The container and its contents are then weighed to the nearest hundredth of a gram, and this weight recorded as "t".

Calculations:

$$\text{Apparent Specific Gravity} = \frac{(S.\ G.)_p\ r}{(S.\ G.)_p\ 500 - (t\ b\ r)}$$

Calibration of Paraffin Oil:

A. Weigh a clean, dry 50 ml volumetric flask to the nearest ten thousandth of a gram and record weight as "W"$_B$.

B. Being careful not to touch the flask with bare hands, pipet in 50 ml of room temperature paraffin oil and allow to sit undisturbed for at least four hours. Recheck colum at this time.

C. Weigh flask and paraffin oil to nearest ten thousandth of a gram and record weight as "W"$_T$.

D. Specific Gravity = $\dfrac{W_T - W_B}{50}$

HEATING VALUE

The heating value, calorific value or Btu content of refuse or residue can be determined by using one of several different types of bomb calorimeters. No standard methods have been developed for determining the heating value of solid waste, but some techniques have been used for determining this value in coal and coke. Common methods are oxygen bomb calorimetry, peroxide bomb calorimetry. The method described here will be the peroxide bomb technique (Parr 1932, 1960).

Theory:

Solid material is added to a bomb capsule along with powdered sodium peroxide and potassium perchlorate. The material is ignited by electrical input, and oxygen is released by decomposition of reagents. The gaseous products of combustion are immediately absorbed and a solid fusion cake is formed in the cup bottom. The fusion consists of excess sodium peroxide, sodium hydroxide, and other sodium salts. The temperature rises very rapidly, and the heat is dissipated into the water shell surrounding the bomb. The rise in temperature is recorded over the period of temperature rise and fall. The charge must be finely pulverized and throughly intermixed in order that all material is burned. The more pertinent reactions are as follows:

$$C + Na_2O_2 \longrightarrow CO_2 + 2\ Na_2O \longrightarrow Na_2CO_3 + Na_2O$$

$$H_2 + Na_2O_2 \longrightarrow H_2O + Na_2O \longrightarrow 2\ NaOH$$

$CH_4 + 4\ Na_2O_2 \quad CO_2 + H_2O + 4\ Na_2O$

$Na_2CO_3 + 4\ NaOH + Na_2O$

$S + 3\ Na_2O_2 \quad SO_2 + Na_2O_2 + Na_2O \quad Na_2SO_4 + 2\ Na_2O$

Equipment:

A. Peroxide Bomb Calorimeter (Parr Instrument Company)

Procedure:

A. Place 1.0 gram of unburned solid waste or 2.0 gram of incinerator residue in the calorimeter fusion cup.

B. Add 0.5 gram of potassium perchlorate, 0.2 gram of benzoic acid and about 15 grams of sodium peroxide to the cup. Thoroughly mix all ingredients.

C. Fill the calorimeter bucket with 2000 ml of distilled water and assemble the calorimeter.

D. Ignite the mixture.

E. Take temperature readings at 30 second intermals until a maximum temperature is reached.

F. Continue to take readings until the temperature drops.

G. Disassemble the bomb and save the fusion by dissolving it in 150 ml of distilled water.

Corrections:

Several chemical reactions take place within the bomb. These do not occur in the normal conbustion of fuels. Since they involve heat in the bomb, this heat must be subtracted from the total heat output of the bomb. Corrections for each of these side reactions are conveniently expressed by the indicated degrees Fahrenheit.

Fuse wire and electrical resistance	0.005°F
Ash-multiply % by	0.005°F
Sulfur-multiply % by	0.005°F
Acceleration, 1.000 gram potassium perchlorate	0.200°F
Benzoic acid - total rise for combustion and hydration of 0.3000 gram	2.3.3°F

Hydration factor for 0.500 gram sample of bituminous coals, high and low volatile coke	0.070°F
Sub-bituminous coals	0.170°F
Lignites	0.220°F
Petroleum Coke	0.070°F
Anthracites and coke	None

A. Fuse wire correction - compensates for heat generated by electrical resistance of fuse and oxidation of wire itself.

B. Ash correction - for chemical reactions between the ash and alkali fusion which do not occur during normal burning of the fuel. In general the ash correction for coal and coke is somewhat different from the solid waste correction. The correction is based upon the interreaction of alkali metals with the peroxide to form alkali-hydroxides. For refuse, correct by multiplying percent ash by 0.10.

C. Sulfur correction - in normal conbustion the $S + SO_2$, while in the peroxide bomb $S + SO_3$. The additional heat released must be subtracted.

D. Accelerator correction - the accelerator, potassium perchlorate, decomposes and releases considerable heat.

E. Benzoic acid - the benzoic acid itself is converted to CO_2 and H_2O. The water released hydrates the sodium oxide. The correction for both combustion and hydration must be made. If less than 0.3 gram is used, the correction should be determined experimentally.

F. Hydration factor - in the combustion of organic constituents, the water formed reacts with alkali present to liberate heat. In normal conbustion process, the water vapor escapes with no further generation of heat. The amount of hydrogen in the sample limits the hydration reaction in the bomb. For solid waste, correct value of sub-bituminous coal by increasing the hydration by an addition of 0.03°F for each multiple of one-half gram. For residue samples, decrease the hydration value by 0.07°F to 0.100°F for each sample multiple of one half gram.

G. Temperature Correction:

1. Thermometer Scale Corrections:

   Corrections are necessary to compensate for slight irregularities in the bore of the thermometer and for inaccuracies in graduations. Use the correction chart which is furnished with the calorimetric thermometer.

2. Radiation Corrections:

Actual Temperature Rise = (T Final - T Initial) + Radiation Correction

If heat is lost by the calorimeter due to radiation and conduction, then the ture temperature rise would be greater than the observed rise and the correction must be added or subtracted.

To simplify calculations, it is recommended that the starting water temperature be adjusted to 1.5° - 2.0°F below ambient temperature. At end of the first minute after ignition, calorimeter temperature becomes approximately 1.5°-2.0°F above room temperature. Hence, heat loss and gain during the first minute cancel each other. The method of calculation can be shown graphically in Figure A - 3. The radiation correction is obtained by averaging the temperature drop after the water temperature has reached a maximum.

Calculations:

$$\text{Calorific Value} = \frac{(0.73)\ (\text{Water Equiv.})\ (\text{Corrected Temp. Rise})}{\text{Wt. Sample}}$$

For 0.500 gram of sample, the equations may be reduced to the following:

$$\text{Calorific Value} = \frac{(0.73)\ (2123.3)\ (\text{Corrected Temp. Rise})}{0.5000}$$

These equations can be explained by the following consideration.

The water equivalent accounts for:

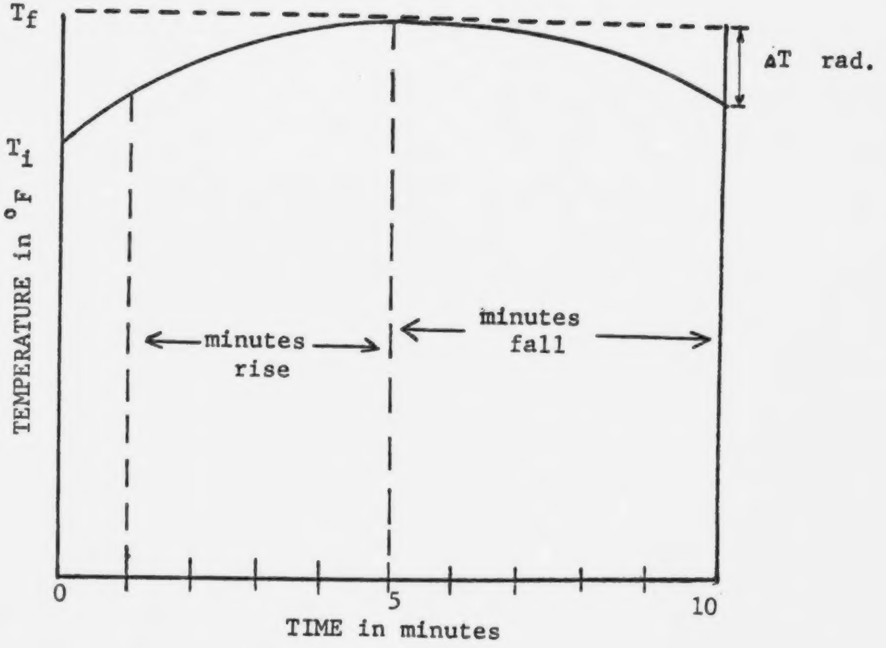
a. The heat capacity of the water and metal calorimeter parts.

b. The Weight of the test sample to be used.

c. The heat liberated in the sodium peroxide bomb by reactions which do not occur in the normal burning of a fuel.

thus, total weight of initial calorimeter parts which are heated by combustion is approximately 1370 grams. Assuming average specific heat of 0.090 yields a water equivalent of 123.3 for the metal parts. When this is added to the 2000 grams of water in the calorimeter, a total water equivalent of 2123.3 is obtained.

If this value is multiplied by the observed temperature rise, the total heat units liberated in the bomb is obtained. It has been found



BOMB CALORIMETER TEMPERATURE CORRECTION PROCEDURE

FIGURE A - 3

that 27 percent of the heat developed by the total reaction is due to the heat of the reaction of CO_2 and H_2O with Na_2O. Hence, the heat liberated by the combustion of the test sample is only 73 percent of the total.

SULFUR

Sulfur can be determined by several methods of varying degrees of complexity. The following method uses the combustion of solid material (raw refuse or incinerated residue) in a constant volume peroxide bomb. The resulting chemical reaction is the formation of sodium sulfate in an alkaline fusion. The sulfate content can be determined by either a turbidimetric method (7) or gravimetrically (26).

Equipment:

A. Parr Sulfur Bomb

B. Spectrophotometer

C. 500 ml Beaker

Procedure:

A. Weigh two to three grams of finely pulverozed sample and place in the bomb.

B. Add one scoop of sodium peroxide and 1.0 gram of potassium perchlorate.

C. Place bomb in moving water bath and ignite. Allow the bomb to cool.

D. Dissolve the fusion in 200 ml of idstilled water (sulfate free).

E. Measure 100 ml of sample, or a suitable aliquot made up to 100 ml, into a 250 ml erlenmeyer flask. Add exactly 5.00 ml of conditioning reagent and mix. While the solution is being stirred, add a spoonful if barium chloride crystals and begin the timing immediately. Stir for exactly one minute at a constant speed.

F. Immediately after the stirring period has ended, pour some of the solution into the cell of the photometer and measure the turbidity at 30 second intervals for four minutes. Maximum turbidity is usually obtained within two minutes, and the readings remain constant thereafter for three to ten minutes. Consider the turbidity to be the maximum reading obtained in the four minute interval.

G. Estimate the sulfate concentration in the sample by comparing the turbidity reading with a standard curve secured by carrying out the procedure with standard sulfate solutions. A suitable range of standards extends from 0 to 40 mg/l of sulfate ion in 5 mg/l increments. Above 40 mg/l the accuracy of the method decreases, and the suspensions of barium sulfate lose stability.

Conditioning Reagent:

Mix 50 ml glycerol with a solution containing 30 ml concentrated HCl, 300 ml distilled water, 100 ml 95 percent ethyl or isopropyl alcohol, and 75 grams sodium chloride.

Calculations:

$$\text{Percent Sulfur} = \frac{\text{mg } SO_4 \times 200 \text{ ml} \times 10}{\text{ml Sample} \times \text{Sample Weight in Grams}}$$

CARBON-HYDROGEN ANALYSIS

Analytical procedures for the determination of carbon and hydrogen generally involve combustion followed by a method to quantify the products of combustion: carbon dioxide and water vapor. Modifications of the basic Pregal procedure can be purchased as self-contained units. However, the sample size used in these units is too small to be used for macrodetermination of carbon and hydrogen in refuse or residue.

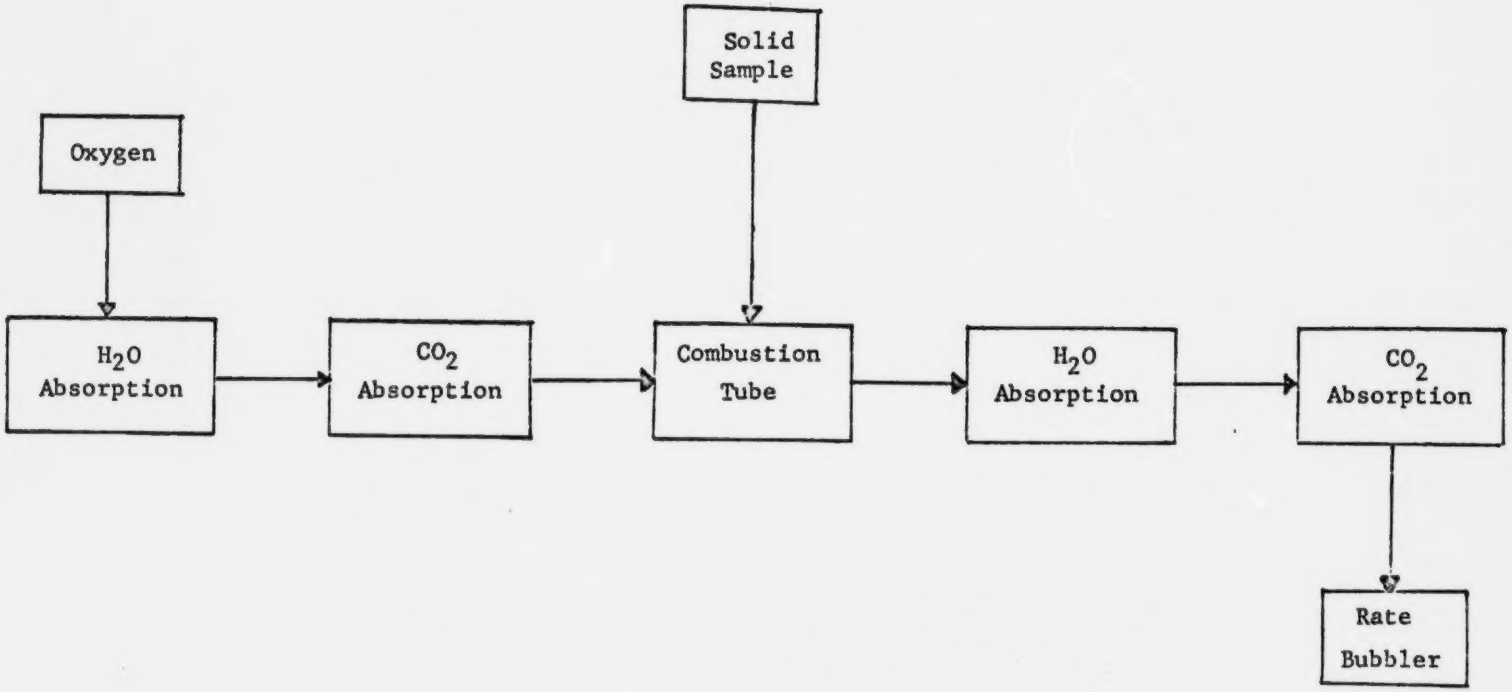
Available literature on the microdetermination of carbon and hydrogen is voluminous and Steyermark (36) lists 392 references for the chapter on carbon and hydrogen. While this large resource of information exists, application procedures to the macrodetermination of carbon is a heterogenous compound is scarce. In order to develop a method for the macrodetermination of carbon and hydrogen, it was necessary to begin with basic principles and develop a technique which could be successfully used. Figure A-4 shows the basic principles considered in developing the method.

The principle of carbon and hydrogen determination is the conversion of carbon and hydrogen in the presence of heat to carbon dioxide and water vapor.

$$C + O_2 \longrightarrow CO_2 \quad \text{-----------------} \quad A - 1$$

$$H_2 + 1/2\ O_2 \longrightarrow H_2O \quad \text{-----------------} \quad A - 2$$

If the sample is accurately weighed, and the above products of combustion are collected, then a materials balance can be performed, and the


Oxygen
H_2O Absorption
CO_2 Absorption
Solid Sample
Combustion Tube
H_2O Absorption
CO_2 Absorption
Rate Bubbler

CARBON - HYDROGEN METHOD
BASIC PRINCIPLES
FIGURE A - 4

percent of carbon and hydrogen determined. Combustion must be in a pure oxygen atmosphere. In the classical procedure the water vapor is abosrbed by magnesium perchlorate (Dehydrite) (4) while the carbon dioxide is absorbed by sodium hydroxide on asbestos (Ascanite) (6).

When the compound being analyzed is essentially pure, i.e. homogenous, then fewer difficulties are encountered. However, refuse and residue contain inferring substances such as chloride, alkali earth metals and sulfur. In order to eliminate the effect of interferring sustances, catalysts are used. The catalysts proposed by Coleman (8), Steyermark (36), Belcher and Spooner (4) and Grace and Gauger (13) are presented in Table A - 1.

The size of the combustion tube as recommended for the microdetermination of carbon and hydrogen is either 9 mm inside diameter (4) or 8 mm (36). A tube of this small diameter does not have sufficient volume for complete combustion of large samples. In addition, a large sample boat could severly restrict the gas passage through the tube. In order to circumvent the small size tube difficulty a tube of 1 - 7/8 inches inside diameter was chosen. Figure A - 5 shows the dimensions of the combustion tube as well as the packing catalysts which were ultimately chosen.

TABLE A - 1

SUMMARY OF RECOMMENDED CATALYSTS IN DETERMINATION OF CARBON AND HYDROGEN

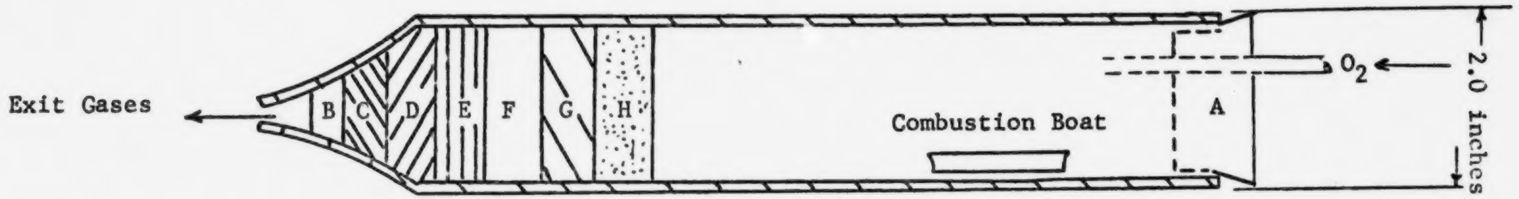
Catalyst	Recommended By	Reason for Selection
Silver Gauze or Turnings	1, 2, 3, 4	Reaction with halogens and sulfur. Also temperature elevation at tube exit.
Copper Oxide	1, 2, 4	Oxidizing agent and gaseous dispenser.
Silver Vandate	1	Reaction with sulfur and halogens.
Lead Chromate	2, 4	Oxidizing agent.
Lead Peroxide	4	Retains oxides of nitrogen.
Platinum	1, 4	Catalytic oxidation of ringed compounds.
Potassium Dichromate or Vanadium Pentoxide	4	To prevent formation of carbonate in presence of alkali earth metals.

1 Reference Number 8

2 Reference Number 13

3 Reference Number 4

4 Reference Number 36


Exit Gases
B
C
D
E
F
G
H
Combustion Boat
A
O_2
2.0 inches

A. No. 10½ Heat Resistant Rubber Stopper
B. Silver Gauze
C. Quartz Wool Plug
D. Copper Oxide - Oxidizing Agent
E. Silver Vanadate
F. Lead Chromate
G. Potassium Dichromate
H. Platinized Asbestos

COMBUSTION TUBE PACKING ASSEMBLY
CARBON - HYDROGEN ANALYSIS
FIGURE A - 5

IRON

Iron is a large constituent of refuse and residue. Iron is found in several valence states, and the interaction of iron with the environment occurs mostly in the form of compounds which are soluble in water.

Several methods are available for determining the quantity of iron: polarographic, colorimetric and atomic absorption analyses.

Sample Preparation:

There are two techniques which are used to prepare the samples for iron analysis. The two methods are similar in that strong acids are used for digestion. Sulfuric acid digestion cannot be used for the atomic absorption procedure because of the buildup of metallic sulfates in the combustion chamber. For atomic absorption the hydrochloric acid method must be used.

A. Sulfuric Acid Digestion:

1. To a ml Kjeldahl flask add about five grams of sample and 50 ml concentrated sulfuric acid.
2. Heat the mixture for three hours, and allow it to cool.
3. Cautiously add concentrated aqueous ammonia until the solution is basic (to litmus).
4. Transfer the solution to a 400 ml beaker and adjust the pH to 8.2 with concentrated aqueous ammonia.
5. Filter the precipitate formed using Whatman #41 and suction filtration. Wash with copious volumes of deionized water.
6. Dissolve the precipitate and filter paper in 100 ml of 50% HCl. Heat gently for complete solution and cool.
7. Filter the solution and discard the residue. Dilute the filtrate to 250 ml in a volumetric flask.

B. Hydrochloric Acid Digestion:

1. Add five grams of residue to 100 ml of concentrated hydrochloric acid. Cover with a watch glass and place on a hot plate under an operating hood for three hours. Keep careful watch on the acid since it evaporates quickly.

2. Cool and filter the sample.

3. Dilute the filtrate to 250 ml in a volumetric flask.

Procedure:

A. Colorimetric:

1. Pipet a 100 lambda aliquot into a clean 100 ml volumetric flask.

2. Add about 50 ml of distilled water.

3. Add one ml each of sodium acetate and ammonium hydroxide-hydrochloric acid reagents.

4. Add ten ml of phenanthroline and dilute with water to the volume.

5. Let the color develop for about fifteen minutes. Read absorbance at 508 mu.

6. Run a concurrent blank with distilled water.

7. Calculate iron concentration by comparing the abosrbance with the standard curve.

B. Polarographic Analysis:

1. Pipette 5.0 ml of sample into 50 ml of 0.5 M sodium citrate containing 0.005 percent gelatin. Adjust pH to 5.8 with hydrochloric acid or aqueous ammonia.

2. Dilute to 100 ml and run on polarograph

3. Calculation

$$\text{Percent Iron} = \frac{(\text{Reading from Curve}) \times 2.79 \times 10^4}{\text{Sample Weight}}$$

Standard Curve:

A. Solutions:

1. Stock Iron: Add slowly 20 ml H_2SO_4 to 50 ml distilled water and dissolve 0.7022 gm Fe $(NH_4)_2$ $(SO_4)_2 \cdot 6H_2O$. Add dropwise 0.1 N $KMNO_4$ until a faint pink color persists. Dilute with distilled water to 500 ml. This solution contains 0.2 mg (0.0002 gm) / ml.

2. Standard Iron: Pipet 25 ml of STOCK IRON solution into a 500 ml volumetric flask and dilute to the 500 ml mark. This solution contains 0.01 mg Fe / ml.

3. $NH_2OH \cdot HCl$: Dissolve 56 gm in 500 ml water. Prepare fresh every few days.

4. Phenanthroline: Dissolve 0.5 gm 1,10 phenanthroline, $(C_{12}H_8N_2 \cdot H_2O)$ in 500 ml distilled water. Add a few drops concentrated HCl to facilitate dissolution.

5. Sodium Acetate: Dissolve 200 gm $NaC_2H_8O_2 \cdot 3H_2O$ in 800 ml distilled water.

B. Preparation of Calibration Curves:

Pipet 5, 10, 15, 20, 25, and 30 ml of the standard iron solution into 100 ml volumetric flasks. Add 2.0 ml of $NH_2OH \cdot HCl$ solution and 2.0 ml $NaC_2H_8O_2 \cdot 3H_2O$ solution to each flask. Dilute each to about 75 ml with distilled water, add 10 ml phenanthroline solution, dilute to volume, mix thoroughly and let stand for 10 minutes. Measure the absorbance of each solution in a 1 cm cell at 508 mu against a reference blank prepared by treating distilled water with all reagent standards except the standared iron.

POTASSIUM

EDTA METHOD

The EDTA method can be used to determine the amount of potassium in aqueous samples. This method requires a longer time to perform than does the determination of potassium using a specific ion electrode.

Reagents:

A. Sodium Tetraphenyl Boron Solution: Dissolve 23 grams sodium tetraphenyl boron in about 800 ml. of water. Add 20-25 grams reagent grade Al $(OH)_3$, stir for 10 minutes and filter. Collect the first 100 ml. of filtrate separately for refiltration. Dilute the clear filtrate to 1 liter.

B. Ethylenediaminetetraacetic Acid (EDTA) Solution: Dissolve 40 grams of the disodium salt of EDTA in distilled water and make up to 1 liter.

C. 40% Sodium Hydroxide Solution: Dissolve 40 grams reagent grade NaOH in distilled water and make up to 100 ml.

D. Wash Solution: Add 0.10 gm. $(C_6H_5)_4$ BNa to 900 ml. water. Stir occasionally for 30 minutes. Add 5 gm. Al $(OH)_3$. Stir for 5 minutes and filter. Dilute filtrate to 1 liter.

Procedure:

A. Transfer 25 to 50 cc. aliquot of filtrate prepared under initial preparation to a 250 ml. beaker. Make slightly alkaline with ammonium carbonate. Filter as necessary.

B. Add 10-25 ml. EDTA solution, 5-10 ml. 36% formaldehyde, 2-5 ml. 40% NaOH, and 100 ml. distilled water.

C. Slowly, and with constant stirring, add 1 ml. of sodium tetraphenyl boron solution for each 2 mg. potassium suspected in the sample, plus 10 ml. to provide an excess.

D. Let stand for 5-10 minutes and filter through a fritted glass drucible.

E. Wash all traces of the precipitate from the beaker with 5 ml. portions of wash solution. A total of 50 ml. of wash solution should be used.

F. Wash the precipitate with 5 ml. of distilled water, dry at 110 C, cool, and weigh.

G. Dissolve the precipitate in acetone, rinse the crucible with distilled water, and dry at 110 c. Cool and weigh.

H. Run a blank on reagents.

Calculations:

$$\frac{\text{Weight of Ppt.} - \text{Weight of Blank} \times 13.143}{\text{Weight of Sample in Grams}} = \text{Percent } K_2O$$

MOISTURE CONTENT

The moisture content of refuse is used in the operation of an indinerator. Moisture determines the amount of excess air and dictates when the use of auxilary fuel is required. Several methods of determining moisture are presented in this appendix. One method appears in the section on Modified Proximate Analysis, and a second procedure is found under the Karl Fischer Technique.

The xylene method which is given here is an azrotropic distillation technique. The original procedure used toluene as the solvent, but the high toxicity of toluene suggested that another compound might be used. This method is recommended for use in determining the moisture of raw refuse since no low boiling point compounds are evolved by drying at 100°C.

Reagents:

A. Xylene - technical grade is acceptable.

Apparatus:

A. Round bottom flask, 500 ml

B. Dean Stark trap

C. Condenser

D. Heat source, preferably a hot plate, but if an open flame is used, wire guaze is mandatory

E. Boiling chips

Procedure:

A. 1. Place about 50.0 grams of sample of refuse into a dry 500 ml round bottom flask.

2. Fill half-full with xylene; add boiling chips

3. Attach Dean Stark trap to flask, all xylene to the trap until it overflows into the flask.

4. Attach the condenser to the trap.

B. Reflux for one hour.

C. Allow to cool. Displace any water that has collected on the inside of the condenser with fresh xylene.

D. Record the volume of water in the bottom of the trap.

Calculations:

$$\text{Percent Moisture} = \frac{\text{Volume of Water in ml}}{\text{Sample Weight in gm}} \times 100$$

MOISTURE-DETERMINATION
KARL FISCHER TECHNIQUE

The Karl Fischer Technique has been used to determine the percent of moisture in material where standard moisture tests are not applicable. The technique uses the Karl Fischer Reagent which absorbs moisture from the sample. The reagent is standardized against methanol.

The Standardization of Karl Fischer Reagent

The sodium tartrate dihydrate sample for standardization is determined from the water equivalence of the Karl Fischer reagent and the size of the buret used, since one gram of this salt contains 156.6 mg of water. For example, using a reagent with an equivalence of 5 mg of water per ml, a 300 mg sample would react with 9.4 ml of reagent (which is about maximum for a 10 ml buret). The following formula for the water equivalence is used for the direct titration:

$$\text{mg } H_2O\text{/ml KF reagent} = \frac{\text{wt. of dehydrate mg. x 156.6}}{\text{ml KF reagent}}$$

Preparing the pH Meter for Electrode Titrations

Karl Fischer and other polarized electrode titrations can be performed with an expanded scale ph meter but its current of polarization must be known.

1. Connect a shorting lead from the pH input to one of the polarizing current connectors (KF).

2. One platimum electrode should be connected with the other polarizing current connector (KF) and a second platinum electrode plugged into the reference electrode connector (REF). The electrodes can then be lowered into the sample.

3. Set the scale expand switch to the 0-14 (normal) position. Set the function switch to the millivolt position. The potential measured using the above procedure is only a relative value. If the absolute potential point with the polarizing current flowing is required, it may be determined by traveling together, in the open air, the tips of the platinum electrodes after they have been connected as described. The expand switch should be in the 0-14 (normal) position and function switch in the millivolt position. The reading on the lower scale will indicate the true potential point, which should be at approximately mid-scale.

The following procedure is to be followed prior to titrating:

a. Allow the pH meter to warm for one hour.

b. Wash the receiver jar of the apparatus. Rinse with acetone and place in the oven for 15 minutes.

c. The electrodes must be clean and dry before titrating. If the electrodes contain iodine from a previous titration clean them by dipping in acetone and allowing to dry in air for 15 minutes.

d. Place a clean, dry magnetic stirring bar into the receiver jar and attach the jar to the electrode housing.

e. Pump 50 mls of methanol into one of the automatic zer burettes.

f. Place a total of 150 mls of methanol into the receiver jar and turn on the magnetic stirrer.

g. Fill the second burette with 50 mls of Karl Fischer reagent.

h. Allow the Karl Fischer reagent to enter the jar.

i. When the tips of the electrodes touches the liquids the ph meter should register - 1130 millivolts. As each succeeding drop of Karl Fischer reagent enters the receiver jar and disperses the pointer will begin to fluctuate. It will fluctuate between-1130 and -930 millivolts.

j. When - 930 millivolts is reached and maintained for 15 seconds, the end point has been reached.

k. At this point the reading on the burette containing the Karl Fischer is noted.

The unknown sample can now be added to receiver jar:

a. When the sample is added and allowed to mix thoroughly, the pointer will return to -1130 millivolts.

b. Titrate as above until a second -930 millivolts is reached and maintained for 15 seconds.

c. Note: the number of mls of Karl Fischer reagent used for the titration of the unknown sample.

Calculations

$$\text{mg } H_2O \text{ / ml methanol} = \frac{\text{ml KF reagent x equivalence}}{\text{ml methanol}}$$

Given: 1 mg H_2O / ml methanol

$$\text{\% water} = \frac{\text{ml KF reagent x equivalence}}{\text{weight of sample in grams x 10}}$$

PHOSPHORUS (P_2O_5)

Phosphorus in solid waste is useful as an indicator of the background availability of this nutrient for plant growth. It is expected that the concentration will be small, and too small a concentration will mean that this element will have to be added for proper plant growth. The procedure presented has been used for phosphorus in raw refuse (5).

Initial Preparation:

A. Dry, cool, and weigh a crucible. Add about three grams of the prepared sample. Five replicates of each sample should be performed.

B. Dry the sample and crucible in an oven at 100°C for 2 hours or until constant weight. Cool in a desiccator and weigh.

C. Transfer the fried sample to an 800 ml Kjeldahl flask, and add about 40 ml of concentrated sulfuric acid and a few glass beads.

D. Boil in a fume hood until the organic matter is destroyed (until liquor becomes straw-colored). Cool and rinse (not beads) into a 200 ml volumetric flask. Add about 80 ml of distilled water.

E. Make the solution alkaline with strong NaOH using phenolphthalein as the indicator. Add hydroxide until solution just turns pink.

F. Make up to the mark with distilled water and mix thoroughly.

G. Filter the 200 ml and store.

Procedure:

A. Pipette ten ml of the filtrate prepared as directed under initial preparation into a 100 ml beaker.

B. Add 30 ml of ammonium molybdate solution (5 gm ammonium molybdate in one liter of 0.75 N HCl).

C. Add 10 ml of elon solution (10 gm of elon in one liter of 3% $NaHSO_3$).

D. Mix thoroughly and let stand from 20 to 30 minutes before determining phosphorus with a spectrophotometer. Read at 735 mu.

E. Make up solutions for standard curve in the same manner, adding reagents in the amounts necessary to make up to 50 ml volume. Standards contain 100, 80, 60, 40 and 20 ppm P, respectively. Other standards or dilution of samples may be necessary depending upon the material being analyzed.

F. Prepare a chart or curve of percent absorbance versus grams phosphate in the original sample tested.

Calculations:

$$\text{Percent } P_2O_5 = \frac{\text{Grams of } P_2O_5 \text{ (Taken from Chart or Curve)}}{\text{Weight of Sample (gm)}} \times 100$$

BIOCHEMICAL OXYGEN DEMAND

Biochemical Oxygen Demand is a measure of the amount of oxygen necessary to stabilize waters containing soluble material which can be used as food for microorganisms. Water has a saturation limit for dissolved oxygen, and the limit varies with temperature. In the test procedure, samples of the polluted water are prepared at several levels of dilution and seeded with a known group of sewage microorganisms. The samples are then incubated for a five day period of 20°C. At the end of the five days the amount of oxygen uptake is measured and the BOD computed. The procedure discussed is found in Standard Methods (33).

Apparatus:

A. Incubation bottles: 250 to 300 ml capacity with ground glass stoppers. Clean with detergent, rinse, and drain. Use a water seal to prevent against drawing air into the bottle. The seal may be obtained by inverting the bottle in a water bath.

B. Air incubator: thermostatically controlled at 20°C ± 1°C. All light should be excluded to prevent diurnal cycle of DO by algae in samples.

Reagents:

A. Distilled water for solutions and dilutions. The water should be kept at 20°C.

B. Phosphate buffer: dissolve 8.5 g KH_2PO_4, 21.75 g K_2HPO_4, 33.4 g $Na_2HPO_4 \cdot 7\ H_2O$, and 1.7 g NH_4Cl in 500 ml distilled water and dilute to 1 liter. pH should be 7.2. If dilution water is incubated at 20°C, add buffer prior to using dilution water.

C. Magnesium sulfate: dissolve 22.5 g $MgSO_4 \cdot 7\ H_2O$ in distilled water and dilute to 1 liter.

D. Calcium chloride: dissolve 27.5 g anhydrous calcium chloride in distilled water and dilute to 1 liter.

E. Ferric chloride: dissolve 0.25 g $FeCl_3 \cdot 6 H_2O$ and dilute to 1 liter.

F. Acid or alkali: 1 N solutions to neutralize acid or alkaline leachates.

G. Sodium sulfite: dissolve 1.575 g anhydrous Na_2SO_3 in 1 liter of distilled water. Solution is unstable and must be prepared daily.

H. Seeding material: use 20 ml / liter of sewage influent or 25 ml / liter of sewage effluent.

Procedure for Preparation:

A. Preparation of dilution water: distilled water should be stored in cotton-plugged bottles to become saturated with oxygen or may be partially aerated. Distilled water should be at 20 C and of high purity. Place the desired volume of distilled water in a suitable bottle and add 1 ml each of phosphate buffer, magnesium sulfate, calcium chloride, and ferric chloride for each liter of water.

B. Seeding: if necessary the dilution water is seeded with sewage effluent. Seeded dilution water should be used the same day it is made.

C. Pretreatment: the leachate samples will probably be basic. Neutralize to a pH of 7.0 with 1 N sulfuric acid using a pH meter.

D. Dilution technique: make several dilutions on the leachate of from one to ten percent.

   1. Siphon dilution water, plus seed if necessary into a graduated cylinder filling it half full. Add desired quantity of sample to obtain the desired dilution. Mix with rod (plunger) and prevent aeration. Divide in half, one for 5 day BOD and one for initial dissolved oxygen (IDO).

   2. Technique is simplified by adding sample to bottles of known volume with a large tip volumetric pipet or graduated cylinder. Fill bottle so that stopper can be inserted without leaving bubbles of air in the bottle.

   3. Make one bottle using only dilution water.

E. Incubation: incubate the blank and dilution samples for 5 days at 20°C. Determine the DO using the permanganate modification of the iodometric method. Dilutions showing a residual of at least 2 mg / liter should be considered the most reliable.

F. Seed correction: if water is seeded set up a volumetric series on the seed sample starting with a solution of 25 ml / liter of sewage effluent. Mix dilutions with phosphate buffer, magnesium sulfate, calcium chloride, and ferric chloride. Incubate at 20°C. Use that dilution which gives 7 - 8 ml / liter of oxygen in 5 days. Use this correction in determining the 5 day BOD.

G. Dilution water control: fill BOD bottles with upseeded dilution water. Stopper and water seal one bottle for incubation. The other is used as the initial DO. This should not be more than 0.1 ml - 0.2 ml. This is not a blank correction.

Calculations:

A. IDO mg / 1 - Final DO mg / 1 = ____________

B. IDO mg / 1 Seed - Final DO mg / 1 = ____________

C. Difference (A - B) = ____________

D. C x Dilution Factor = Five Day BOD

CARBOHYDRATE

Carbohydrates are present in refuse and incinerator residue as cellulose, sugars and starch. Sugars will be found in all forms, and the concentration of each is not known. Many test procedures for carbohydrates are specific, but the analytical procedure which is used must be of a general nature rather than for determination of a specific carbohydrate group.[1] The method presented here is the Anthrone Calorimetric Method, which is applicable to sugars and starch. Cellulose is not determined by this method.

Apparatus:

A. Ice Bath

B. Boiling water bath (constant temperature)

C. Spectrophotometer

D. Chromic acid cleaned glassware

E. Soxhlet extraction apparatus

Reagents:

A. Anthrone Reagent: 0.2 percent anthrone (9, 10-dehydro- 9 oxoanthracene) in 95 percent sulfuric acid. This solution is unstable and must be prepared daily.

B. Standard glucose solution for preparation of standard curve.

---

[1] For a detailed discussion of the relative analytical techniques refer to: Whistler, Roy L. and Wolfram, M. L., *Methods in Carbohydrate Chemistry, Volume I, Analysis and Preparation of Sugars,* Academic Press, New York, 1962.

Procedure:

A. Sample Preparation:

1. Place 50 grams of solid sample in a pre-weighed and dried extraction thimble.

2. Extract for three hours in a Soxhlet extraction apparatus at a rate of five cycles per hour.

3. Cool the solvent and filter through a Buchner funnel using glass wool as the mat.

B. Standard Curve:

1. Prepare standard glucose solutions of 0.05, 0.10, 0.15 and 0.2 mg/l glucose.

2. To four ml. of standard solution add six ml. of acidified anthrone reagent. Cool immediately in an ice bath.

3. Place in boiling water for ten minutes.

4. Cool immediately in an ice bath.

5. Prepare a blank solution of six ml. anthrone and four ml. distilled water.

6. Read the optical density at 625 mu.

7. Plot a standard curve for the glucose solutions vs. absorbance.

C. Sample Analysis:

1. Follow the procedure for preparation of the standard curve, except substitution of several sample dilutions is made for the standard glucose. If a white precipitate develops, centrifuge the sample and use the supernatant for reading the absorbance.

D. Calculations:

1. The carbohydrate concentration can be obtained directly from the standard curve.

KJELDAHL NITROGEN

Kjeldahl nitrogen is a procedure used to determine the amount of total organic nitrogen in solid waste or aqueous samples. The organic forms of nitrogen which are measured by this test include protein nitrogen and its degradation products: amino acids and peptides.

Procedure:

A. Dry 0.1 - 0.5 gm sample at 105°C until constant weight is reached. Place sample into 500 ml flask (Kjeldahl). Add 40 ml concentrated sulfuric acid, 26.8 gm potassium sulfate, and six ml mercuric sulfate. Digest slowly until frothing ceases, and for 20 minutes after the liquid becomes "water clear".

B. Cool and dilute to 350 ml with distilled water.

C. Make alkaline with hydroxide - thiosulfate solution using phenolphthalein as an indicator. Distill into 50 ml of boric acid solution until 200 ml distillate has been collected. The temperature in the condenser should not rise above 29°C.

D. Titrate the ammonia with 0.02 N sulfuric acid until the indicator turns a pale lavender. Run a blank on the reagents used and correct.

Calculations:

$$\text{mg/l Organic N} = \frac{\text{ml } H_2SO_4 \text{ for Sample} - \text{ml } H_2SO_4 \text{ for Blank}}{\text{ml Sample}} \times 280$$

Standard Solutions:

A. Hydroxide-thiosulfate: Dissolve 500 g NaOH and 25 g $NaS_2O_3.5\ H_2O$ in distilled water and dilute to one liter.

B. Boric Acid Solution: 20 g boric acid plus 10 ml of mixed indicator and dilute to 1 liter.

C. Mixed Indicator: Two volumes of 0.2% methyl red, one volume of 0.2% methylene blue in 95% ethyl alcohol.

PROTEIN

Determination of protein can be done by using several methods. In raw refuse a fixed ratio exists between the amount of organic nitrogen and the concentration of protein. For raw refuse protein can be calculated from the concentration of organic nitrogen (5). In incinerator residue the fixed ratio between protein and nitrogen does not exist and both quantities must be determined separately. The Biuret technique is presented for determining protein in residue. Protein is first extracted in the water soluble fraction, and the Biuret method used on the water soluble fraction.

Apparatus:

A. Constant temperature bath at 37°C.

B. Spectrophotometer

Reagents:

A. Biuret Solution

1. Sodium tartrate - 9.0 gm
2. Copper sulfate - 1.0 gm
3. Potassium iodide- 1.0 gm
4. 0.2 N sodium hydroxide

Dissolve the solid reagents in 40 ml of the sodium hydroxide and dilute to 200 ml with the 0.2 N sodium hydroxide.

Blank:

Prepare a protein blank using egg albumin as the standard. Make up standard dilutions ranging in concentration from 50 to 400 mg/1.

Procedure:

A. Add six ml of reagent to four ml of sample.

B. Incubate at 37°C for 30 minutes.

  1. If the sample develops a white colloid, it may be necessary to centrifuge the sample. Decant the clear solution and continue.

C. Place the sample in a cuvette and read the percent transmission at 550 mu.

D. Run a duplicate on distilled water.

Calculations:

A. Plot a standard curve of percent absorbance against protein concentration in mg/l.

B. The quantity of protein can be read directly from the standard curve.

SODIUM AND POTASSIUM

Analyses of leachate from sanitary landfills indicate that the concentrations of sodium and potassium are above the quantity found in sewage. These compounds affect the ecology of surface streams and impart taste to waters used as a potable source. The following procedure assumes that sodium and potassium compounds are soluble in water.

Procedure:

A. From the filtrate of the water soluble fraction transfer 100 ml into a volumetric flask.

B. Place the solution into a 150 ml beaker and adjust to pH 9 - 10 with a $Ba(OH)_2$ solution.

C. Replace the glass electrode with a K-sensitive electrode. Using the expanded scale read millivolts.

D. Using a graph of millivolts vs. equivalents of K (on semi-log paper), find the equivalents of K in solution.

E. Replace the K-sensitive electrode with a Na-sensitive electrode. Using the expanded scale, read millivolts.

F. Using the graph of millivolts vs. equivalents of Na on semi-log paper, find the equivalents of Na in the solution.

G. From the results in mg/l, claculate the quantity of sodium and potassium as percent by dry weight of sample.

WATER SOLUBLE FRACTION

The water soluble fraction is that portion of refuse or residue which can be directly implicated in the pollution of ground and surface waters. It is desired to find not only the quantity but also the composition of the water soluble fraction.

1. Weight out 250 grams of residue and place in a drying oven at 70°C. When the sample of residue has obtained constant weight, remove from the drying oven.
2. Place 2000 ml of distilled water in a beaker.
3. Place the 250 grams of residue into the 2000 ml of distilled water and stir for one hour. The dry weight of the residue should have been obtained before placing into the beaker.
4. After stirring for one hour, remove the residue and beaker from the stirrer and filter the mixture through a large glass funnel. After the entire mixture has been filtered, remove the filtered material and place in a drying oven at 70°C. for one day. Obtain the weight of the residue after this one day drying.
5. The difference in weight will be the water soluble fraction of the residue.

Phosphorus (P_2O_5)

Initial Preparation:

1. Dry, cool, and weigh a crucible. Add about 3 grams of the sample prepared as directed under Sample Preparation.
2. Dry in an oven at $70^\circ C$ for 2 hours, or until constant weight. Cool in a dessicator and weigh.
3. Transfer the dried sample to an 800 ml. Kjeldahl flask and add about 40 ml. of concentrated H_2SO_4 and a few boiling beads.
4. Boil in a fume hood until the organic matter is destroyed (until liquor becomes a straw-colored). Cool and rinse (not the beads) into a 200 ml. volumetric flask. Add about 80 ml. of distilled water.
5. Make alkaline with strong NaOH using phenolphthalein as the indicator. Add hydroxide until solution just turns pink.
6. Make up to the mark with distilled water and mix thoroughly.
7. Filter the 200 ml. and store. This filtrate is now ready to be used for the determination of both phosphorus and potassium.

Metho 1: Follow steps 5 through 12 as given on page 75 of Laboratory Manual for Chemical and Bacterial Analysis of Water and Sewage, Theroux, Eldridge, and Mallman, McGraw-Hill Book Co., Inc., New York, 1943.

Phosphorus (Continued):

Method 2:

1. Pipette 10 ml. of the filtrate prepared as directed under initial preparation into a 100 ml. beaker.
2. Add 30 ml. of ammonium molybdate solution (5 gm. ammonium molybdate in one liter of 0.75 N HCl).
3. Add 10 ml. of elon solution (10 gm. of elon in one liter of 3% $NaHSO_3$).
4. Mix thoroughly and let stand from 20 to 30 minutes before determining phosphorus with a spectrophotometer or colorimeter apparatus.
5. Make up solutions for standard curves in the same manner, adding reagents in the amounts necessary to make up to 50 ml. volume. Standards contain 100, 80, 60, 40, and 20 ppm phosphorus, respectively. Other standards or dilution of samples may be necessary depending on the material being analyzed.
6. Prepare a chart or curve of %transmittance versus grams P_2O_5 in the original sample tested.
7. Calculations:

$$\frac{\text{Grams of } P_2O_5 \text{ (taken from chart or curve)} \times 100}{\text{Weight of sample (gms.)}} = \% \ P_2O_5$$

APPENDIX B

METHODS OF SAMPLING

SOLID WASTE SAMPLING TECHNIQUES

In order to predict the character and behavior of solid waste materials it is necessary to determine with statistical reliability the exact chemical and physical composition of the waste materials. Solid waste materials are generally random in composition and some parameters such as moisture, extend over a wide range of values on a daily basis. Other changes in the composition, such as the percent of plastic matter, are occurring slowly and the trends cannot be discerned over a short period of time. Many years, perhaps even a decade, will be required to show the change in composition of these minor components.

Previous Work

For purposes of analyzing a single sample or a series of small samples several researchers employed techniques which met the demands of the system being studied. Bell[1] in his sampling of the City of Milwaukee used several cubic yards and quartered the refuse to a quantity of about one cubic yard. The glass and metals were removed before the remaining wastes were shredded in a mill. By extracting the glass and metals the resulting sample could have been biased for moisture and organic matter are adsorbed on the surface of the inert matter. Removal of the organic material in the sample can change the overall characteristics of solid waste, especially with respect to odor.

Kaiser[2], in one study used only a single sample of more than one cubic yard and separated the waste into fractions of paper, rags, metal, etc. The choice of a large sample is necessary and desirable, but the unit cost of analyzing such a sample is prohibitive, and therefore this technique probably is not applicable to comprehensive studies, such as nationwide data gathering network.

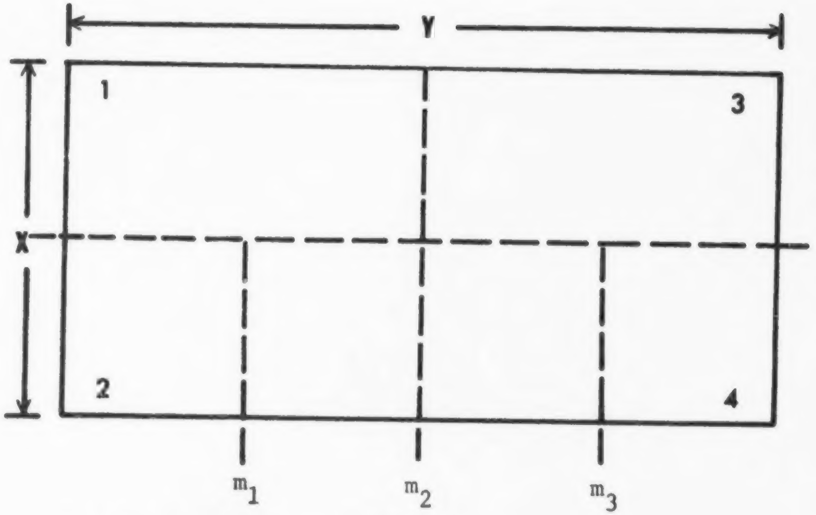
Other techniques including the Quad-City study,[3] used schemes for sampling, but the refinement of sampling methods is still being pursued. All systems have some drawbacks either as to sample size needed or to sample accuracy.

In order to develop sampling procedures which are both statistically acceptable and yet not too costly, several schemes are given in this paper which were used to sample raw refuse and incinerator residue in the Philadelphia area.

Raw Refuse

Domestic refuse samples are taken to determine the chemical and physical properties of refuse which is charged to an incinerator or which is disposed of in a sanitary landfill. Domestic wastes are variable in composition and their generation variables extend to all corners of the U.S.A. A sampling procedure which is applicable to determine the character of the wastes throughout the United States is desirable. If it is assumed as reported by Mix[4], that 800,000 tons of refuse are produced daily and further assume that the average unit weight is 200 pounds per cubic yard, then the volume of wastes generated daily is eight million cubic yards. To obtain a statistically representative sample of this large waste volume is almost impossible. If the sample size taken is only 0.1 percent, 800 tons of refuse must be sampled daily. These 800 tons must be taken randomly and simply establishing an experiment to taken random samples across the United Staes is uneconomical. If, as required by sampling theory, the collection of samples is random, the sampling teams may have to travel from city to city on a daily basis or have many teams located in different geographical areas. Assuming that sampling could be accomplished, the logistics of chemical analysis remain unsolved. Even if the samples are considered drawn from an infinite population, the accuracy of the results will not be known until after the sampling and analysis is completed.

The procedure presented for sampling of raw refuse was developed for use with either collection system sample or from an incinerator with an operation program as developed by the Public Health Service. The two techniques are slightly different, but both yield good results.



N = Total Number of Samples
M = Total along Horizontal Axis
$M = (Y/X - 1)$

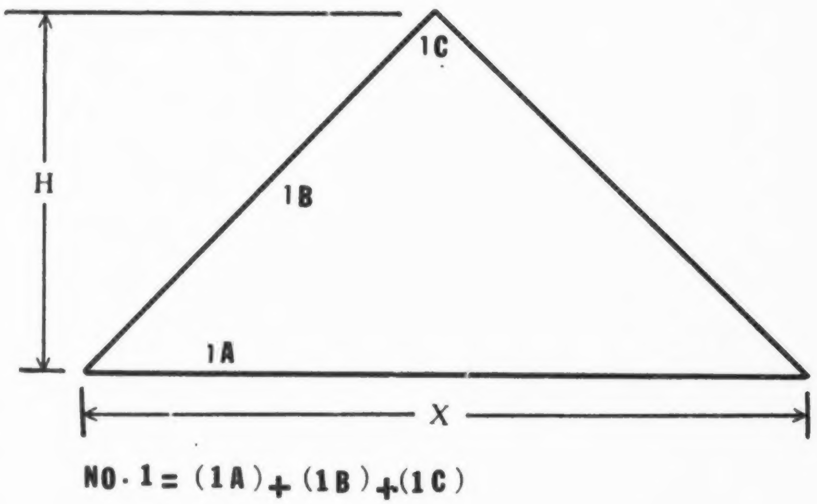
SAMPLING POINTS FROM RESIDUE OR REFUSE PILE - PLAN VIEW

FIGURE NUMBER 1

Collection System Sampling

To obtain samples from the collection system the sampling is done by randomly selecting the trucks used on the route. The number of trucks chosen will vary with the initial results of analysis. In order to check the sampling it is necessary to choose a parameter which can be used to predict the accuracy of the sampling. For large quantities of waste this can be a simple test such as the loss on ignition or the fraction which is soluble in organic solvent. Moisture content is not a good parameter, since there are too many external variables which affect the moisture content.

In order to sample from the trucks it is necessary that the trucks dump the load upon a flat surface, preferably concrete for simplified cleanup afterwards, and then take the samples from the piles as shown in Figure Number 1. To avoid the intermixing and placing on concentric circles as proposed by the Quad City Study[3], it is required that the refuse be deposited upon the flat surface and that the length and width of the pile be measured. When the pile is arranged as in Figure Number 1, samples are teken from the four corners as shown. From each corner a thirty pound sample is taken and placed either in a truck or in containers for future combining with the samples from the other locations. Figure Number 2 shows the vertical


H
1C
1B
1A
X
NO. 1 = (1A) + (1B) + (1C)

SAMPLING FROM RESIDUE OR REFUSE PILE - VERTICAL END

FIGURE NUMBER 2

N = Total Number of Samples
M = Total along Horizontal Axis
M = (Y/X + 1)

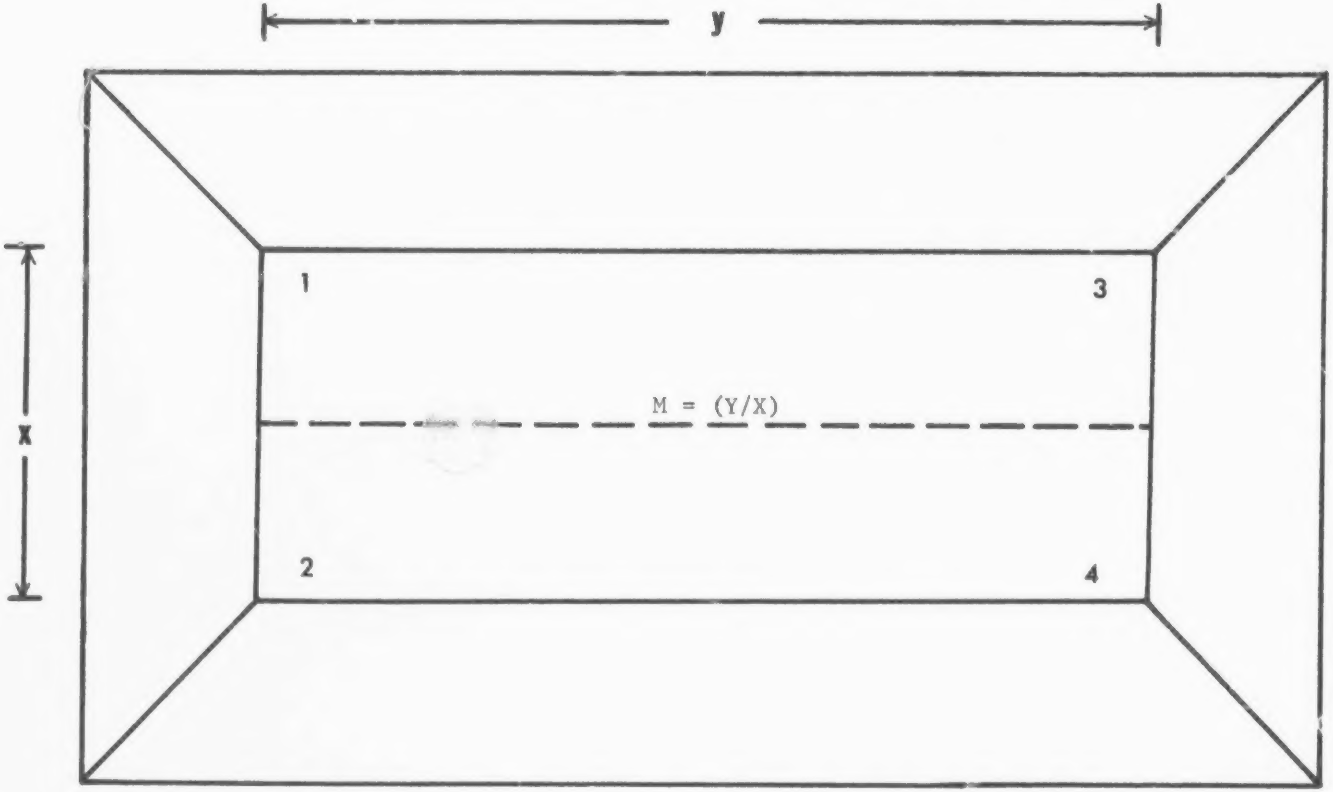
SAMPLING POINTS FROM RESIDUE OR REFUSE PILE - PLAN VIEW

FIGURE NUMBER 1

No. 1 = (1A) + (1B) + (1C)

SAMPLING FROM RESIDUE OR REFUSE PILE - VERTICAL END

FIGURE NUMBER 2



N = M ÷ 4
N = Total Number of Samples
M = Number of Samples along Longest Axis

SAMPLING POINTS FROM INCINERATOR HOPPER - PLAN

FIGURE NUMBER 3

distribution of the waste and where the thirty pound sample is collected in ten pound aliquots at each of the three vertical sampling points. Samples at all four corners are collected in the same fashion.

In addition to sampling at the corners it is necessary to obtain samples from the centerline of the pile. The number of centerline samples is calculated by dividing the length of the pile by the width in feel plus one.

$$M = (Y/X+1) \text{ ------------ } (1)$$

Refuse Sampling from an Incinerator

In the standard test procedure of the Public Health Service for determining the operating efficiency of incinerators, it is required that samples of the refuse charged and residue discharged from the incinerator be collected and analyzed.

An open body truck is maneuvered into a position where it can be filled with refuse by the crane. The weight of refuse on the truck is determined by subtracting the vehicle tare weight into the charging hopper. The charged refuse weight is determined by wieghing the refuse remaining at the end of the test. For each crane bucket of refuse charged into the incinerator, a small sample is taken at the charging hopper. One cubic foot is taken from each of the four corners and one cubic foot samples are taken from the longitudinal axis as shown in Figure Number 3. All cubic foot samples are mixed together during grinding.

N = M + 4
N = Total Number of Samples
M = Number of Samples along Longest Axis

SAMPLING POINTS FROM INCINERATOR HOPPER - PLAN

FIGURE NUMBFR 3

Figure Number 3 shows all points of sampling from an incinerator charge hopper. Weighing the refuse before charging can be eliminated if only refuse samples are desired or if incinerator operation is not being monitored.

Residue Sampling

Sampling of incinerator residue is required when it is desired to analyze the residue produced under a given set of operating conditions. If the sample is to reflect residue character under a set of operating conditions, then the furnace retention time must be estimated. For example, at a design capacity of 12 tons per hour for a continuous feed incinerator, it requires several minutes for the refuse to reach the grate from the charging chute, and several minutes to traverse the combustion chamber. Thus, the sampling procedure must be offset to account for this retention time.

The sampling of residue in the proposed system is done on one truck of residue, since sampling directly from the discharge hopper is difficult and impractical. The trucks contain residue from a long period of operation and generally contain a broader sample base than direct sampling. Sampling occurs after the residue is damped on the ground. Individual samples are taken from each of the corners and at eight foot intervals along the longitudinal axis. Approximately 25 to 50 pounds of wet residue are taken at each sample point. Each point also includes vertical sampling as was shown in Figure Number 2. Thus, from each corner three samples are taken which are then consolidated into a single sample as was done on refuse sampling.

Sample Preparation

Before any analyses can be performed on either incinerator residue or raw refuse, the sample must be homogenized as much as possible and reduced in size. Homogenization can be partially achieved by reducing the particle size through grinding, shredding or crushing, followed by a thorough mixing of the sample. Unless some low boiling point components are vaporized during grinding the weight percentage between the constituents of the solid product should not be effected, but volume relationships will be destroyed.

The samples which were collected of raw refuse or incinerator residue are first pulverized in a general purpose ahmmermill. The mill should reduce the particle size through a combination of impact fracutre and abrasion. After the entire sample is processed, it is thoroughly mixed, and then quartered until about one cubic foot remains. The remaining one cubic foot sample is again processed in a laboratory mill which further reduces the particle size to about a 3/16 inch maximum. This sample is now fully prepared for laboratory analysis.

Secondary Sampling

Secondary sampling is required to obtain from the sample of doubly ground material, an appropriate aliquot for each chemical analysis. Most of the techniques will require a sample of less than 50 grams. The method used to obtain the 50 gm aliquot is to split the sample by means of a riffler which divides the samples into aliquot portions through subsequent passes.

Special Sampling Problems

In sampling residue from an incinerator, care must be taken to perform the material balance on the residue as well as on the excess water used to quench the residue. This excess water leaches material from the residue, thereby subtracting that material from that discharged. Inorganic salts are particularly soluble, but organic matter is also removed. The organic matter plust the soluble salts must be added to the analysis of the residue.

Results of Sampling

Table 1 shows the results of the combustible fraction in incinerator residue and the two sampling techniques for unburned refuse. The various columns are related to the following statistics.

1. No. of Samples: The total number of samples which were drawn and analyzed. Each sample drawn was done in a random way. All samples were drawn in the City of Philadelphia over a period of two years.
2. Total Analyses: After secondary sampling each sample drawn was replicated three to five times, and the number of replicates for all samples is the Total Analyses.

3. Mean: Percent combustible for all analyses including the replicates.

4. Standard Deviation Experimental: This is the standard deviation based on the internal variations in the multiple samples and does not include the components due to variations between samples. The internal variations could be considered as being due to experimental measurement variations as well as lack of homogeneity within the several samples. If the samples are considered to be homogeneous, then this can be considered as the variation due to the measuring technique.

5. Standard Deviation Total: This is the standard deviation based on the internal variation in the multiple samples as well as the variation between samples. This statistic treats the data as if it were one big sample and includes the experimental variation, as well as that due to the heterogenous nature of the sample and the day-to-day variations between samples.

6. Significant Difference Experimental: Differences based on the measurement system and the heterogeneous nature of the samples as calculated on five replicate analyses are shown by this statistic. Any lesser differences could be due to random variation.

7. Significant Differences Total: This is the difference which one can expect to detect, based on the present measuring system, the heterogenous nature of the samples and the day-to-day variation and using a sample consisting of five analysis. Any less differences can be due to random variations.

8. Significant Difference Among All Samples: A value based on the standard analysis of variance where *yes* means that there was a significant difference among the various sample means based on the internal variation within the sample. *No* means that the data did not indicate that there was a significant difference, hence there is no reason to conclude that there is any difference among the sample means. In all cases the level of significance was 0.05, which means there is a 5% chance of making an error when it is concluded that the difference was significant. Where *no* is indicated it simply means that the actual differences which exist could be due to sampling variations or else our measuring variations are too great to detect an actual difference when it exists.

In the results shown in Table B-1 the mean is significant for purposes other than estimating the applicability of the sampling and analytical system. The number of samples and the total analyses show that a total of 75 samples were taken and almost 300 analyses were performed. It was necessary to use this large number of samples in order to get statistical validity.

In all cases, the experimental standard deviation was less than the total standard deviation, which indicates that the error introduced by the analytical and sampling procedures is less than the total variation. The experimental significant different shows that the secondary sampling is not giving homogenous sampling since the error is almost ± 20 percent. It does show that for any given sample of refuse or residue, the results of the analytical determination are probably the reflection of the time values of that sample.

The final line of Table 1 states that there is a difference in character for the samples collected. This is not surprising in that it has been known for a long time that refuse is heterogenous and there is a day-to-day variation in composition. Reasons for this day-to-day variation are attributed to the random nature with which samples were collected. No efforts were made to separate socio-economic effects, seasonal effects or demographic variation.

Summary

Adequate sampling of refuse and residue is a laborous and costly part of any solid waste survey. To help reduce this cost the technique presented is designed to use less manpower than other methods previously used. One person could perform the sampling in about one-half hour. This means that more samples can be taken during any given period of time.

It must be emphasized that the sampling procedure is applicable only for chemical analysis of the refuse or residue. The sample taken is small compared to a compactor truck or a crane bucket used to charge an incinerator. It may be possible to use a manual separation method, but no data are available to either prove or disprove its validity.

TABLE B-1

ANALYTICAL RESULTS OF SAMPLING

	Residue No. 1	Raw Refuse	
		Collection	Incinerator
Percent - Mean Combustible	18.72	48.42	58.16
Number of Samples	43	14	18
Total Analyses	161	51	85
Standard Deviation Experimental	3.3	10.09	5.48
Standard Deviation Total	11.00	21.42	19.18
Significant Difference Experimental	4.09	12.51	6.80
Significant Difference Total	13.64	26.56	23.78
Significant Difference Among All Samples	yes	yes	yes

INCINERATOR-RESIDUE-FILL SITE INVESTIGATION

by

R. J. Schoenberger[1] A.M. ASCE and A. A. Fungaroli[2] M. ASCE

INTRODUCTION

Population growth and the present trend toward concentration of population in relatively small regions requires optimal utilization of available land resources. Complete understanding of how best to utilize land resources in urban areas becomes more significant when it is realized that many of the available sites are presently uneconomical to develop. A recent paper by Rutledge (1) discussed the many facets of marginal land utilization.

Concurrent with the problem of land utilization is the problem of increasing volumes of solid waste which must be disposed of annually. The solid waste disposal problem is a result of population growth and concentrations, as well as the population's generally increasing affluence. Figures 1A and 1B (2) indicate predicted per capita and total production of refuse in the United States to the year 1990. It can be seen that the generation of solid waste, and the ensuing disposal problem is compounding.

The most popular method of solid waste disposal is burial at a more or less suitable, but convenient site (a sanitary landfill). Unfortunately, the sanitary landfill disposal method may result in surface and ground water pollution (3). Further, reduced land availability adjacent to urban areas requires that new sanitary landfill sites be located in remote locations, and if present patterns hold, these sites may become too distant so as to provide a long-range economical solution. In addition, the generation of gases, such as methane and hydrogen sulfide, in high concentrations and over long periods of time, coupled with long-term surface settlement can limit the use of sanitary landfill sites for major construction.

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To reduce the volume of solid waste which must be disposed of in urban regions and to minimize some of the sanitary landfill objections, incineration of refuse has been practiced for many years. Recently, incineration has been criticized because of the resulting air pollution and the relatively high operating costs due to advanced age of many operating units. Another objection has been the need to dispose of residue from incinerators. However, it is believed that in spite of its present lack of popularity, incineration of some form will continue to be used, particularly as new techniques and facilities become available. Even with the most efficient incinerators, non-combustible residue will result, and the residue must be disposed of by landfilling, either as residue or intermixed with raw refuse.

This paper presents the results of an investigation of an incinerator residue fill site. Included are analyses of the chemical composition of the raw refuse, the incinerator residue prior to landfilling, and the incinerator residue two years after landfilling. Results of an investigation of the physical properties of the two-year-old residue are also presented.

INCINERATION PROCESS

Refuse incineration is performed in two basic types of units: a batch type, where material is charged and allowed to burn down before removal, and a continuous type, where refuse is constantly charged and removed simultaneously.

Figure 2 is a sectional view of a batch feed unit where refuse is dropped into a cylindrical burning chamber. After the refuse has been burned, the residue is removed by dumping the grate into an underlying hopper. A cross-section of a continuous feed incinerator is shown in Figure 3. The unit has two continuously moving chain grates; one inclined and one horizontal. Numerous types of grates and configurations are available. While the choice of design is optional, the degree of burnout (percent of combustible actually burned) is variable, and it is generally acknowledged that the continuous feed system is the more efficient.

Temperatures in the batch system vary from a low of 300°-400°F immediately after charging to a high of 1200°-1500°F before discharge. Continuous feed units are usually operated at temperatures between 1500° and 1900°F. At the higher temperatures, the glass components will fuse and trap other residue components, such as metals, to form large angular masses known as "clinker." Some of the clinker can weigh several hundred pounds.

In both types of incinerators, residue is discharged from the furnace and must be cooled either by spraying the mass with water or by submerging the mass in a water bath. In either case, the moisture content of residue, as it leaves the incinerator, is between 35 and 50 percent.

The residue studied in this investigation was produced in a continuous feed-traveling grate incinerator (Fig. 3) operated by the City of Philadelphia. Physical composition of the raw refuse is presented in Table 1. The results in Table 1 are the average of five manual separations with the refuse sample size being two cubic yards from each compactor truck.

SITE HISTORY

In July 1964, the City of Philadelphia began to use an abandoned water reservoir located in a residential section of the city for the disposal of incinerator residue and a small quantity of old concrete, asphalt, soil, bricks and tree trunks. The reservoir was a soil structure constructed in two sections separated by a soil divider. All soil embankments were constructed of clay with the interior slopes protected by brick rip-rap (Fig. 4).

The reservoir was constructed on the side of a hill with its surface at the same elevation as an adjacent road on the hilltop. One face of the reservoir was completely exposed on the hillside and the reservoir discharge valve was located in its toe. The side topographic features were such that the reservoir was above the ground water table. However, because of the clay liner, surface water which entered the residue was retained. The only water outlet from the reservoir was by evaporation or through the reservoir discharge valve located approximately 15 feet above the reservoir bottom. The discharge valve was closed during this study. The clay liner was impervious, and it is noteworthy that while the reservoir right side was being filled, the left site contained several feet of water, even during the summer.

Three and one-half years were required to fill the reservoir. The fill sequence is shown by the numbers in Figure 4 and the completion date of each section is summarized in Table 2.

Residue was placed by dumping the transport trucks. These trucks carried 25 cubic yards and the gross vehicle weight was between 75,000 and 90,000 pounds.

Compaction of the residue in the landfill was not controlled. Residue was placed by running the loaded trucks across previously deposited residue layers and after being dumped, it was spread with a D-8 bulldozer. Although large pieces of clinker and metal were occasionally in the residue, they did not cause any difficulty in the spreading and compaction operation. The clinker was brittle and quickly fractured under the weight of the dozer. Therefore, no large void spaces were created, nor were any large pieces of glass or metal left near the surface to cause tire-cutting or otherwise impede the travel of rubber-wheeled vehicles on the landfill surface.

Leachate Quantities

Leachate began to discharge from the reservoir near the toe of the exposed face in June 1966. Since that time, leachate flow has been virtually continuous. Table 3 contains leachate quantities and temperatures for the period from February 1967 to December 1969. A V-notch weir was installed to monitor the leachate flow rate.

Leachate Composition

Table 4 presents the composition of a typical leachate. The leachate did not show any large range in quality, despite large variations in quantity.

The nutrient content of the leachate was rather high with the total nitrogen content being almost 200 mg/l. Total solids content of the leachate approximated 8,000 mg/l and the organic oxygen demand was between 1,200 and 1,500 mg/l, as measured by the COD test. The BOD was much lower, primarily because of the large concentration of heavy metals in the leachate. The principal metals were iron, zinc, lead, copper and chromium. Much of the high alkalinity value of 4,260 mg/l was the result of sodium and potassium. Chloride was the major anion present while the sulfate content was relatively low. Because of the dark leachate color, use of colorimetric techniques for analysis were not possible. During the early stages of analysis, this interference created many problems with some of the analytical techniques.

RESIDUE COMPOSITION

Chemical

Table 5 presents chemical analysis data for raw refuse prior to incineration, after incineration but prior to landfilling, and two years after landfill completion.

As refuse is placed in an incinerator the composition of the solid fraction is reasonably predictable. After incineration, most of the organic matter has been burned off and the residue which remains is primarily the inorganic matter. The result of the incineration process is a concentration of the inorganics.

After incineration the pH of the water soluble fraction was predominantly alkaline while the pH of the raw refuse was neutral or slightly acidic. After the material was placed in the field for two years, the pH decreased, because much of the sodium and calcium alkalinity had been leached from the system. This conclusion is substantiated by the dramatic decrease in the sodium content of the residue. Overall, the water soluble fraction decreased from about 5.5 percent to 1.5 percent in two years of uncontrolled leaching.

Behavior of the soluble anions in the system was opposite to the previously described patterns with chloride decreasing, the sulfate remaining stable and the nitrate-nitrogen showing an increase. The chloride decreased by almost 75 percent as would be expected in the solubility system. On the other hand, the cause of the increase in nitrate-nitrogen is not clear. A possible explanation might be that much of the nitrogen present is in a combined organic form, and as the organic matter decomposes, the oxidation of the nitrogen to nitrate results in a natural stabilizing of the nitrogen.

Iron deserves special mention because it is the most prevalent metal in refuse and residue. The decrease in iron content in the residue after two years shows that the residue tends to rapidly reach a state of chemical stabilization and use of the residue for site-development purposes may be possible.

Temperatures

Table 6 presents the results of two vertical temperature profiles taken two years after landfilling. The profiles were taken at two random site locations.

Temperatures in the residue landfill were generally increasing as the depth of the landfill increased. While most of the residue placed in this landfill was low in combustible matter, there was about 10 percent present. This quantity was too low to produce the recorded temperatures by sustained aerobic decomposition. One possible reason for the high temperatures is the black color of the residue which can function as an efficient light energy adsorber.

PHYSICAL PROPERTIES

Borings

Six split-spoon-sample borings (using the standard penetration test) were performed in the residue in the summer of 1969. Table 7 presents the results of this investigation. In general, the blow counts show that the material is loose with extremely dense pockets which may have been small pieces of concrete or tree stumps. Moisture contents ranged between 10.5 and 36.6 percent with a mean of 19.9 percent.

Sieve Analysis

Thirty-three residue samples were sieved using the numbers 4, 10, 20, [illegible], 100 and 200 sieve sizes. The results are summarized in Figure 5. All but two samples fell partly or completely within the dotted band with most of the samples falling within the narrow interior band. One sample fell well-below the band and one sample was well above the band.

The residue can be classified as a well-graded coarse to fine sand size granular type material. Age does not appear to have any marked effect on gradation in as much as the samples were taken from every age deposit within the fill.

Internal Friction

A direct shear test was performed on some residue samples. Initial dry density of the residue was 98.5 pounds/cubic foot. The effective stresses were 10, 20, and 30 psi. ϕ was found to be 45°. While ϕ is large in the light of the blow count and gradation, it probably reflects the high surface angularity of the particles formed during the incineration process.

Compressibility

A stress-strain curve for the material is presented in Figure 6 for a residue sample with an initial dry density of 97.5 pounds/cubic foot. The curve follows an expected pattern and indicates that compressibility characteristics are such as to permit direct support of moderate loads on the residue without excessive total settlement.

In-Place Density

In-place density tests were performed at the surface of the Fairmount Park residue landfill and at a similar residue landfill in northwest Philadelphia. These results are presented in Table 8. Densities ranged between

94.7 pounds/cubic foot and 105.7 pounds/cubic foot with a mean of 101 pounds/cubic foot. Age does not appear to be a significant factor in the residue density, and it is interesting to note that overall there is very little variation in in-situ densities, a point supported by the blow counts in the boring investigation.

Compaction Data

No compaction tests were performed in this study. However, data from a study by Requardt and Harrington (4) is presented because of its relation to the results obtained in this investigation. Two residues from the Requardt and Harrington study are presented. The gradations of the residue are presented in Figure 5. The compaction curves (Standard AASHO Compaction - Method T-99, Method D) are presented in Figures 7 and 8. The residues fell at the lower limit of the gradation band and are considered similar to the residues encountered in this study. The compaction results indicate that the residue has a maximum density of 100 to 102 pounds/cubic foot with an optimum moisture content of from 20-21 percent.

The density and optimum moisture content values are similar to the in-situ values obtained in this study and indicate that during the residue placement, the residue had been compacted to approximately maximum density as a result of the normal placement procedure.

CONCLUSIONS AND DISCUSSION

The use of incinerator residue for landfilled site development is very dependent on the length of time required for its chemical stabilization. The results of this study indicate that within two years 80-90 percent of the soluble material is removed by leaching. These results suggest that optimization of leaching rate could enhance utilization of residue-filled sites for structural development.

The in-situ residue physical properties investigation indicates that the residue was placed at or near its maximum density even though no special compaction procedures were followed. This result suggests that by proper sequencing of residue placement and spreading, maximum densities can be obtained without resorting to special compaction equipment. Hence, use of residue for development of landfill sites should not significantly increase disposal costs.

The split-spoon data suggests that residue-filled sites can have relatively uniform densities if non-incinerated materials are not randomly included. Quality control of in-situ residue placement would minimize potential differential settlements.

The split-spoon data indicates that the incinerator residue is a loose granular material. However, its high angle of internal friction (probably due to the "clinker" surface characteristics) and moderate compressibility indicates that a foundation system directly supported by the residue should be able to safely carry moderate structural loads.

Unlimited use of residue as a fill is not being advocated because at this time no data is available on potential interactions of the leachate chemical components with building materials, such as concrete and asphalt. Concrete is a highly alkaline material which is attacked by low pH liquids. While the pH of the leachate from the incinerator residue landfill was found to be basic, the high concentration of oxygen demanding substances could create pockets of acidic liquid due to the formation of fatty acids, volatile acids or carbonic acid from the solubility of carbon dioxide. If conditions are right, the degradation of the oxygen demanding substances could occur on the surface of concrete, as in a trickling filter or sewer pipe. In concrete sewer pipe the problem of bacterial oxidation of aqueous hydrogen sulfide has caused excessive degradation.

Other chemical components of the residue leachate are of interest when considering possible effects on concrete. The chlorides and nitrates of ammonia, magnesium, aluminum and iron attack concrete (5). In leachate the chloride concentration is several thousand mg/l -- an extremely high concentration. The sulfates of calcium and sodium are also linked with degradation of concrete and these too are present in leachate.

In most cases the concentrations of chemical compounds which will attack concrete must be higher than are found in the leachate. However, the possibility of synergistic interaction is unknown and could result in degradation occurring at lesser concentrations than are found in leachate.

Most of the chemical problems described above can be eliminated by delay of construction until the residue has become chemically stable and by use of concrete protective coatings.

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4. Requardt, G. J. and Harrington, W. M., "Utilization of Incinerator Ash as Landfill Cover Material," American Public Works Association, Annual Yearbook, 1962, p. 216-224.

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TABLE 1

Physical Composition of Raw Refuse
Average Percent Dry Weight

Item	Average Percent Dry
Ferrous Metal	10.92
Non-Ferrous Metal	0.61
Glass and Ceramics	28.41
Non-Combustible Inert	8.71
Rubber	0.39
Rags	4.88
Wood and Cardboard	7.84
Other paper	23.32
Plastic	1.57
Annimal and Vegetable Waste	14.35
Average Percentage of Moisture	30.4

TABLE 2

Filling Sequence

Fairmount Park Incinerator Residue Landfill

Area No.	Date Completed	Approximate Depth (feet)
1	December 1965	30
2	May 1966	20
3	November 1966	10
4	March 1967	15
5	July 1967	25
6	September 1967	35
7	December 1967	10

TABLE 3

LEACHATE TEMPERATURE AND QUANTITY AT TIME OF SAMPLING

Date	Temperature - F°		Flow - GPM
	Ambient	Leachate	
2/27/67	27	94	-
3/2/67	38	94	8
3/20/67	42	111	8
5/3/67	61	103	-
5/18/67	68	110	8
6/6/67	79	97	
6/14/67	74	97	6 - 8
6/21/67	78	100	-
6/26/67	82	96	5
6/27/67	-	-	5
6/29/67	-	96	3.5
7/5/67	-	-	8
7/7/67	80	-	3.5
7/13/67	73	99	3.5
7/18/67	80	-	5.0
7/20/67	-	-	3.5
7/26/67	-	-	1.5
7/27/67	-	-	1.5
8/2/67	80	-	1.5
8/7/67	78	95	3.5
8/14/67	76	105	3.5
8/28/67	72	-	25
9/5/67	81	109	20
10/23/67	68	101	15
3/5/68	51	85	8
6/7/68	-	-	4
6/10/68	-	96	4
6/18/68	-	104	20
9/3/68	-	91	2
11/21/68	-	79	-
12/12/68	41	78	0.5
1/17/69	-	77	1
6/25/69	-	84	1
2/3/69	48	64	1

TABLE 4

Residue Leachate Chemical Composition

pH	8.3
Alkalinity ($CaCO_3$)	4260
Nitrate	3.52
Phosphate	15.21
Iron	4.95
Chloride	1803
Fluoride	5.0
Sulfate	94
Calcium	21
Sodium	3350
Potassium	21.5
Total Dissolved Solids	7933
BOD	125
COD	1265
Zinc	0.95
Copper	1.15
Chromium (total)	1.53
Lead	1.16
Ammonia	47.6
Kjeldahl Nitrogen	124.7

All results stated in mg/l except pH.

TABLE 5

RANGE OF CHEMICAL COMPOSITION OF WATER SOLUBLE COMPONENT OF INCINERATOR RESIDUE

	PRIOR TO INCINERATION	AFTER INCINERATION PRIOR TO LANDFILLING	TWO YEARS AFTER LANDFILLING
pH	5.6-7.2 (6.43)	6.9-11.0 (9.17)	5.94-9.98 (7.94)
Alkalinity (as $CaCO_3$)	0.05-0.32 (0.17)	0.01-0.45 (0.19)	0.003-0.12 (0.038)
Nitrate-Nitrogen	0.00024-0.0016 (0.00066)	0.00008-0.00099 (0.00035)	0.004-0.32 (0.057)
Phosphate	0.00019-0.0042 (0.0010)	0.00021-0.00077 (0.00044)	0.0-0.0017 (0.0003)
Chloride	0.03-4.30 (0.77)	0.03-0.14 (0.08)	0.0002-0.17 (0.027)
Sulfate	0.03-0.12 (0.09)	0.10-0.73 (0.24)	0.007-0.530 (0.25)
Sodium	0.02-0.26 (0.08)	0.01-0.97 (0.20)	0.012-0.30 (0.064)
Potassium	0.01-0.18 (0.07)	0.004-0.14 (0.05)	0.0-0.078 (0.014)
Iron	0.0013-0.027 (0.01)	0.0-0.035 (0.015)	0.0-0.004 (0.0004)
Percent Combustible	35.26-82.95 (58.03)	4.78-17.8 (9.73)	3.2-48.5 (10.0)
Percent Water Soluble	1.27-7.84 (4.82)	1.01-13.76 (5.48)	0.20-4.30 (1.54)

Notes: 1. All quantities in mg/l except pH and percentages.

2. Terms in bracket are averages except pH which is the median.

TABLE 6

INCINERATOR RESIDUE LANDFILL TEMPERATURES

Vertical Profiles-July 29, 1968

Depth - Feet	Temperature - F° Hole 1	Temperature - F° Hole 2
2	-	103
4	101	94
5	119	101
6	125	105
7	124	108
8	-	110
9	125	114
11	134	-
12	141	122
13	-	120
14	142	110
16	147	-

Ambient Temperature - Range 59-83°F, Average 71°F.

Age of Landfill - 2 years.

TABLE 7

INCINERATOR RESIDUE STANDARD PENETRATION AND MOISTURE CONTENT TEST RESULTS

DEPTH (FEET)	BORING NO. 1		2		3		4		5		6	
	w	B	w	B	w	B	w	B	w	B	w	B
5	14.6	20	22.6	13	21.6	12	-	11	28.4 -	3 20 156	19.9	19
10	16.2	3	18.2	6	16.9	15	20.0	6			19.9	8
15	21.0	44	-	2 44	16.9	4 21	25.3	18 R	-	22	14.1	6
20	10.5	47	17.9	3 23	20.0	4 28 R			19.8	9	21.4	10
25	15.6	5	16.9	6					16.6	37 BR	25.9	20
30	33.9	8	17.9	6							25.4	31
35		BR	29.4	17 R							36.6	56 BR

w = Moisture Content - %
B = Standard Penetration Test (140# hammer - 30" drop) Blows/Foot
BR = Bottom of Refuse
R = Refusal

TABLE 8

INPLACE UNIT DRY DENSITY
INCINERATOR RESIDUE LANDFILLS AT SURFACE OF NORTHWEST LANDFILL
AGE 3 YEARS

Test No.	Unit Weight (lbs/ft^2)
1	101.2
2	101.1
3	98.2
4	94.9
5	96.4
6	95.5

INPLACE UNIT DRY DENSITY
INCINERATOR RESIDUE LANDFILLS AT SURFACE OF FAIRMOUNT PARK LANDFILL

Test No.	Unit Weight (lbs/ft^2)	Fill Age at Test
1	105.7	2 months
2	103.5	2 months
3	94.7	1 year
4	99.1	1 year
5	101.3	6 months
6	99.9	6 months
7	100.6	1 year
8	100.9	1 year
9	96.2	2 years
10	103.5	2 years

FIGURE 1A. **UNITED STATES' TREND IN PER CAPITA REFUSE PRODUCTION**

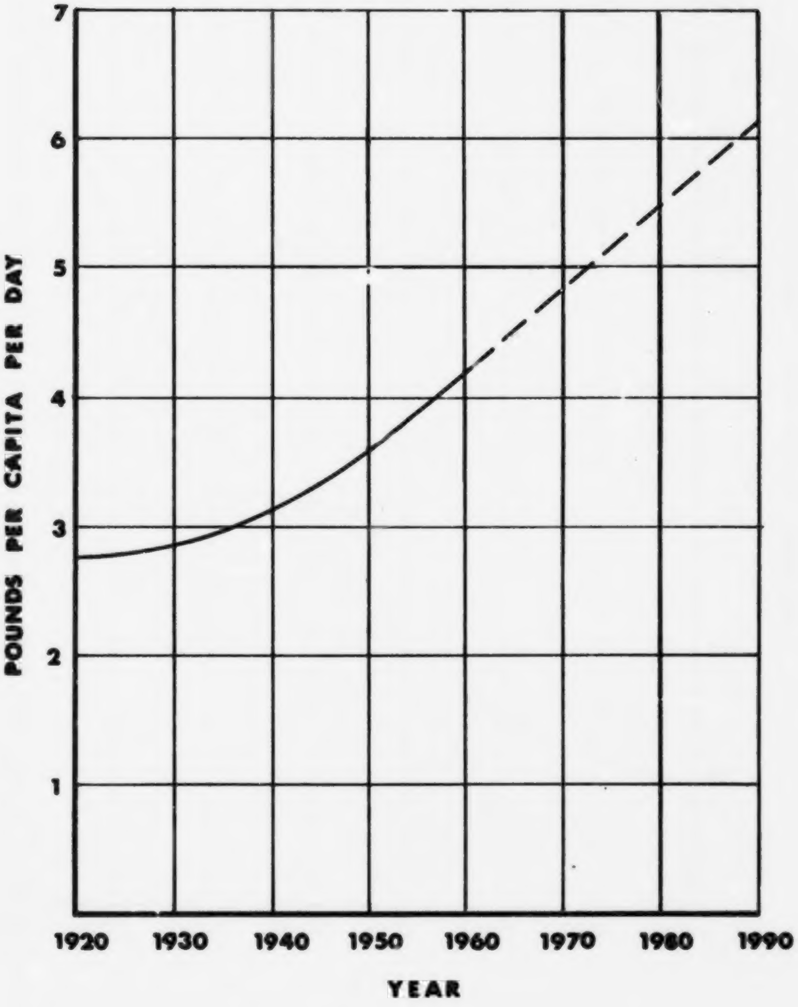
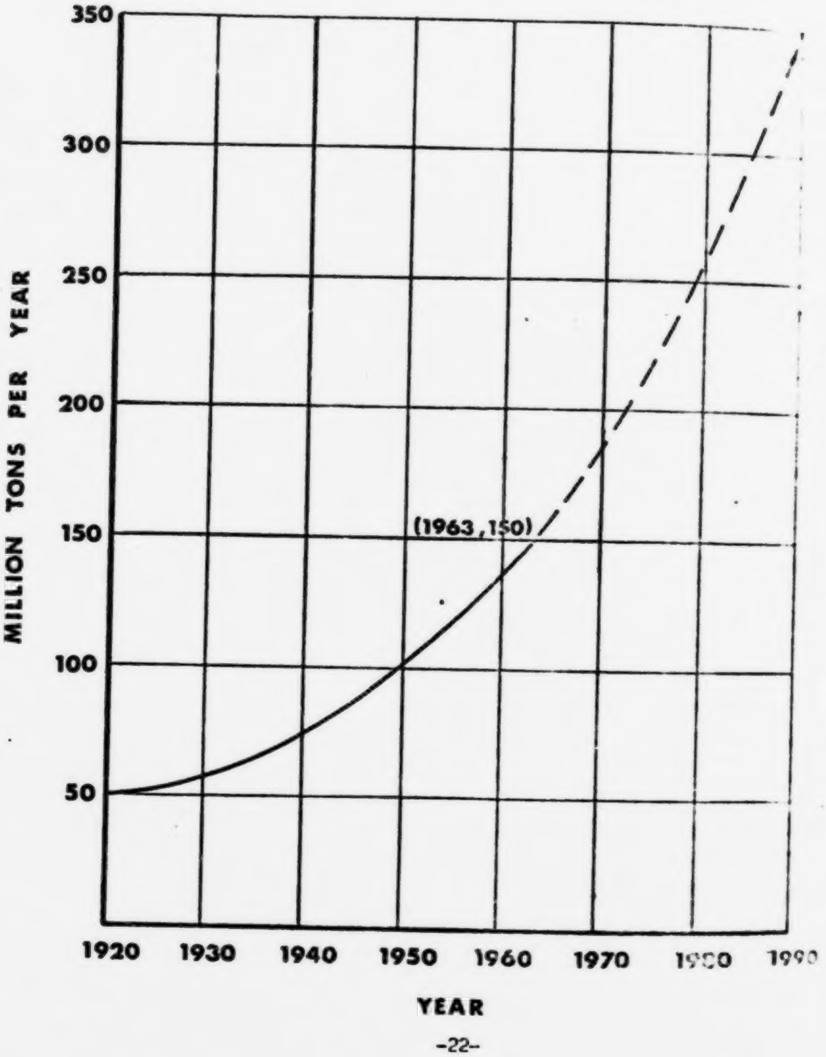


FIGURE 1B. **REFUSE PRODUCTION TRENDS IN THE UNITED STATES**



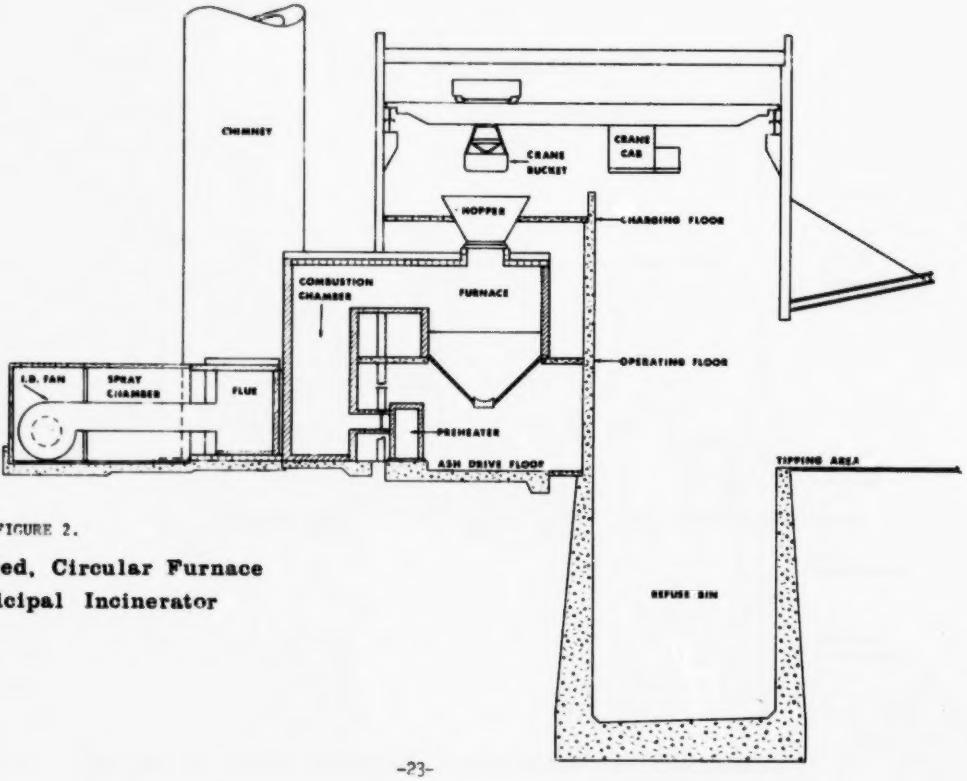

CHIMNEY
CRANE BUCKET
CRANE CAB
HOPPER
CHARGING FLOOR
COMBUSTION CHAMBER
FURNACE
OPERATING FLOOR
I.D. FAN
SPRAY CHAMBER
FLUE
PREHEATER
ASH DRIVE FLOOR
TIPPING AREA
REFUSE BIN

FIGURE 2.

Batch Feed, Circular Furnace
Municipal Incinerator

FIGURE 3. Continuous Feed, Traveling Grate Municipal Incinerator

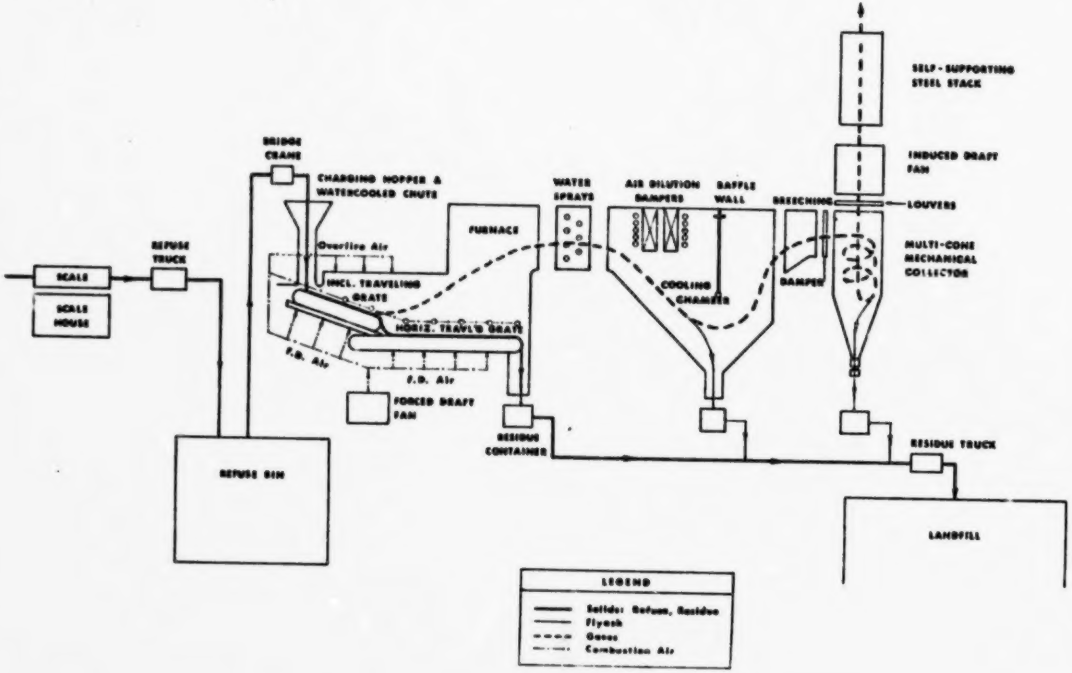

SCALE
SCALE HOUSE
REFUSE TRUCK
REFUSE BIN
BRIDGE CRANE
CHARGING HOPPER & WATERCOOLED CHUTE
Overfire Air
INCL. TRAVELING GRATE
HORIZ. TRAVL'G GRATE
F.D. Air
F.D. Air
FORCED DRAFT FAN
FURNACE
RESIDUE CONTAINER
WATER SPRAYS
AIR DILUTION DAMPERS
BAFFLE WALL
COOLING CHAMBER
BREECHING
DAMPER
LOUVERS
MULTI-CONE MECHANICAL COLLECTOR
INDUCED DRAFT FAN
SELF-SUPPORTING STEEL STACK
RESIDUE TRUCK
LANDFILL
LEGEND
Solids: Refuse, Residue
Flyash
Gases
Combustion Air

FIGURE 4. SCHEMATIC PLAN OF FAIRMOUNT PARK INCINERATOR RESIDUE DISPOSAL SITE.

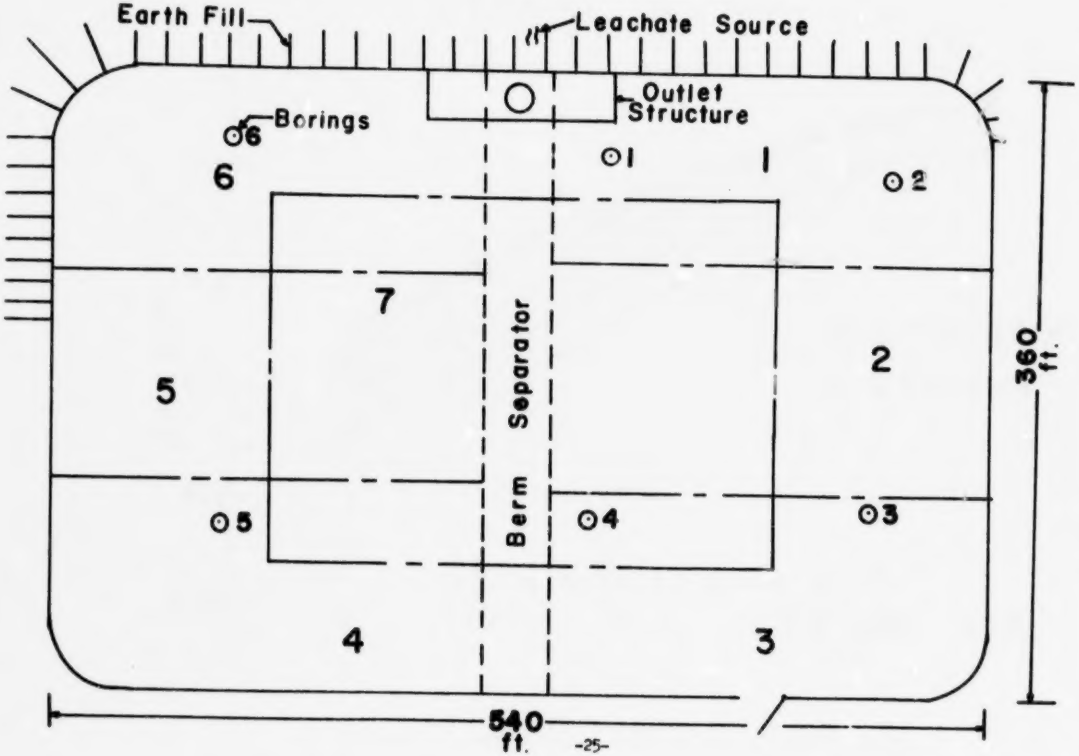
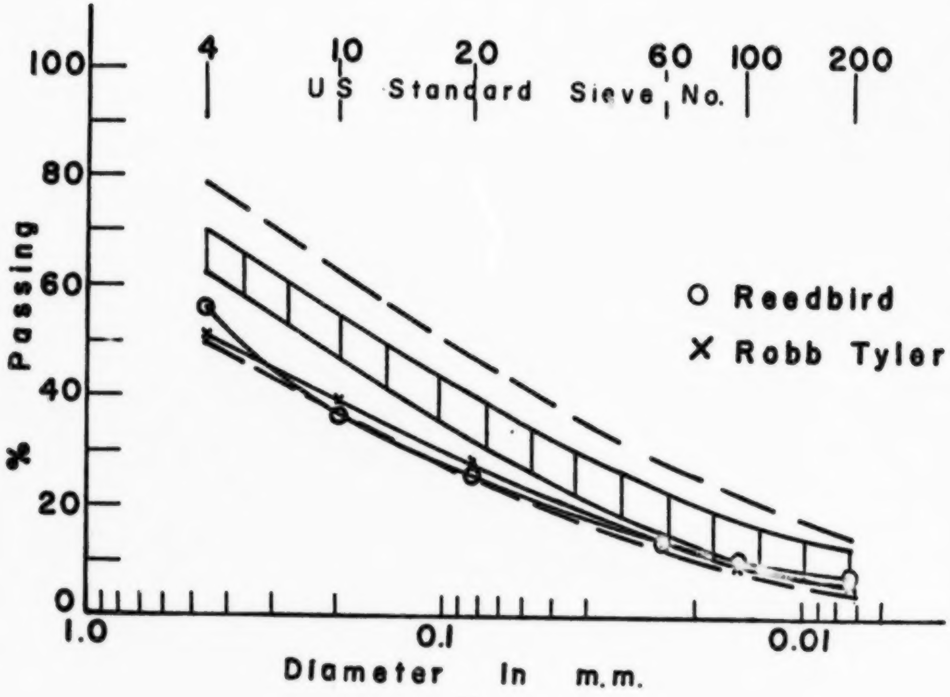

Earth Fill
Leachate Source
Outlet Structure
Borings
6
1
2
7
5
2
Berm Separator
4
3
⊙1
⊙2
⊙3
⊙4
⊙5
⊙6
360 ft.
540 ft.

FIGURE 5. SIEVE ANALYSIS - FAIRMOUNT PARK INCINERATOR RESIDUE
PERCENT PASSING - DIAMETER IN MM



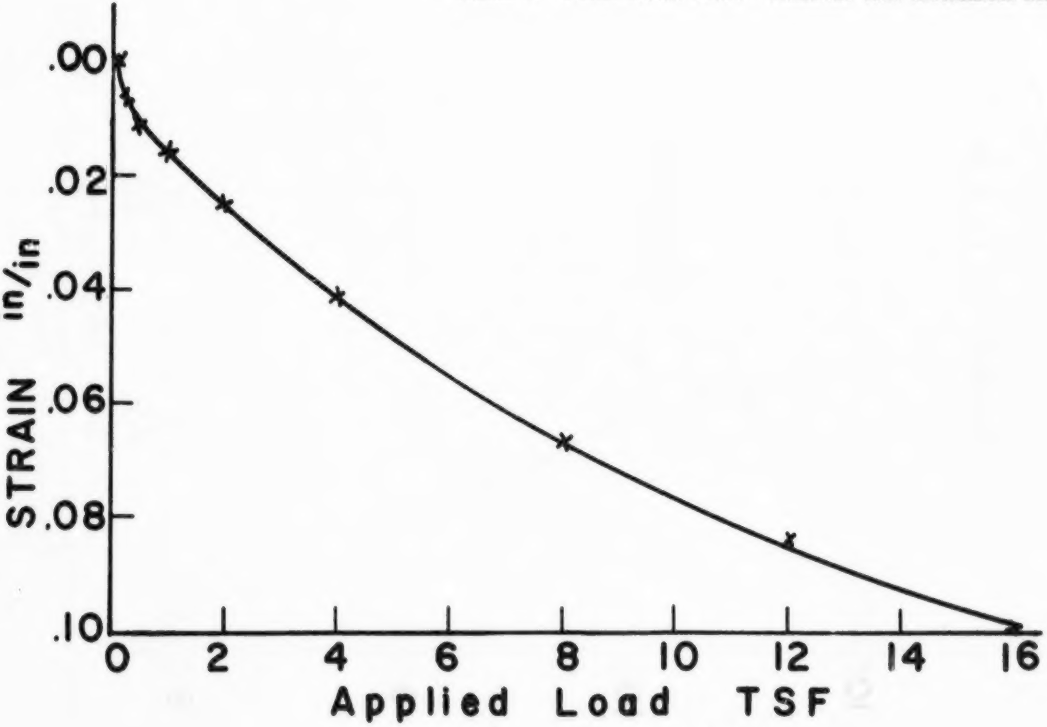


FIGURE 6. STRESS-STRAIN CURVE - FAIRMOUNT PARK INCINERATOR RESIDUE.

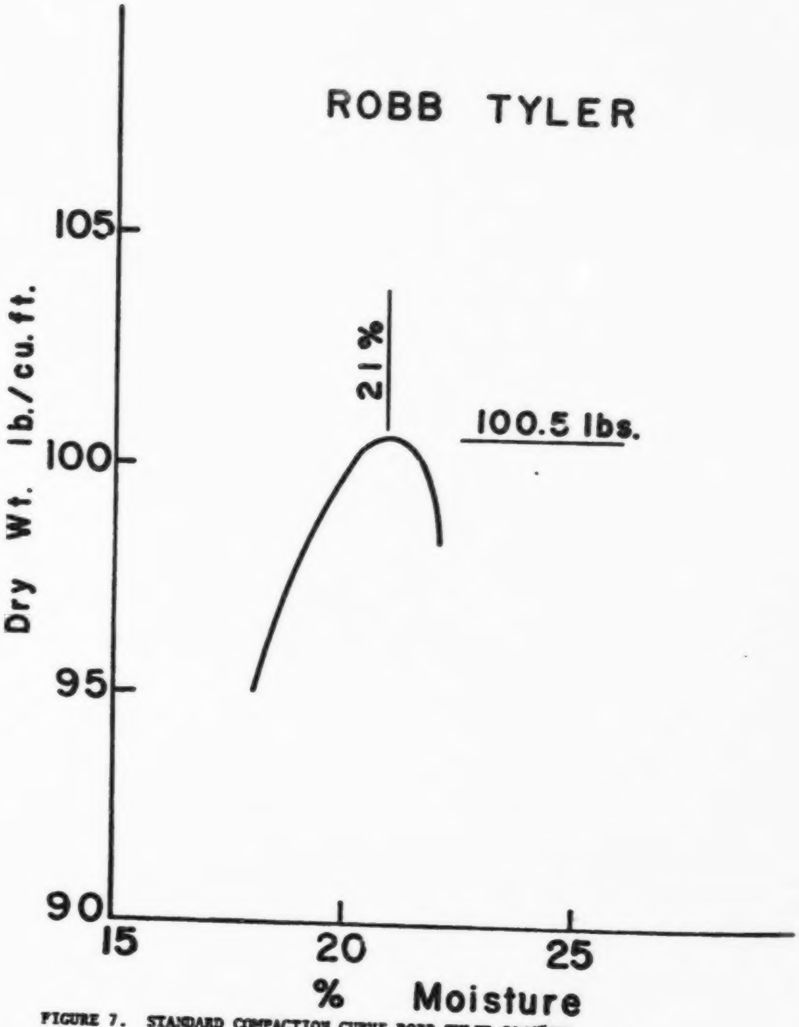


FIGURE 7. STANDARD COMPACTION CURVE ROBB TYLER RESIDUE (From Requardt and Harrington (4)).

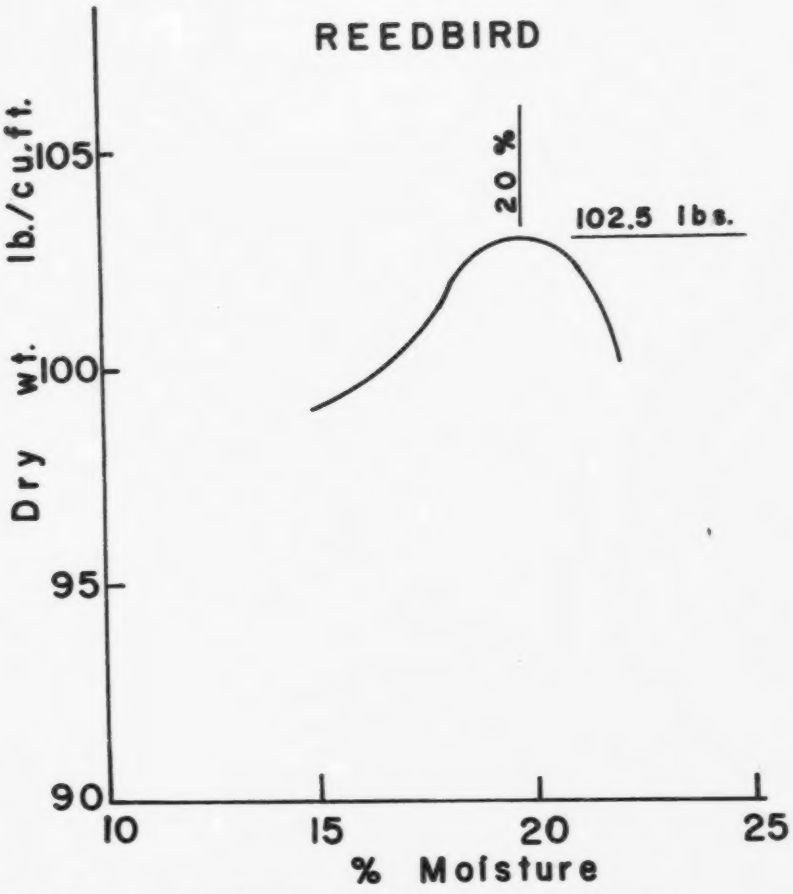


FIGURE 8. STANDARD COMPACTION CURVE REEDBIRD INCINERATOR RESIDUE
(From Requardt and Harrington (4)).